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NOTICES

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NOTICE

This is the final volume of the *New Zealand Journal of Science and Technology,* of which the last issue will appear in December 1957.

It will be replaced in 1958 by three journals:

New Zealand Journal of Agricultural Research,
published in alternate months, first issue February 1958.

New Zealand Journal of Geology and Geophysics,
published quarterly, first issue February 1958.

New Zealand Journal of Science,
published quarterly, first issue March 1958.

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THE EFFECT OF CERTAIN CHEMICALS UPON SPROUTING OF POTATO TUBERS

I. TABLE POTATOES

By C. M. DRIVER, Crop Research Division, Department of Scientific and Industrial Research, Lincoln

(*Received for publication, 10 June 1957*)

Summary

Commercial dusts containing the methyl ester of alphanaphthaleneacetic acid (MANA), tetrachlornitrobenzene (TCN), and isopropylphenylcarbamate (IPPC) have been applied to potato tubers in an attempt to reduce sprouting during storage. The sodium salt of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) has been applied to potato foliage to control sprouting of the subsequent crop.

The three dusts adequately controlled sprouting of the varieties tested at least until early November, and treated tubers were of considerably better quality than untreated at the end of the storage period. The foliage spray, 2,4,5-T, slightly reduced sprouting of potatoes in storage, but reduced yield and caused extensive cracking of tubers. No material tested had any appreciable effect upon the dry matter or the ascorbic acid content of tubers.

INTRODUCTION

Sprouting, and the subsequent rapid deterioration in quality, is a common phenomenon limiting storage time of potatoes. Emilsson (1949) has shown that the period between maturity and sprouting can be divided into a resting period, during which the potato will not sprout even under the influence of optimum growing conditions, and a dormant period, during which the potato can be kept from sprouting by the application of suitable storage conditions. This first period varied from five to sixteen weeks according to variety, and as a consequence it is unnecessary to pay overmuch attention to storage conditions when potatoes are to be stored but a short time after harvest. However, beyond this period storage conditions are very important. Warm, moist conditions may encourage immediate and rapid sprouting, whereas under cool, yet well-aerated conditions, sprouting may be delayed a further three to six months.

In New Zealand, maincrop potatoes are harvested from March to May (or even June), and in the South Island new potatoes do not

replace old ones until late December. Consequently, good storage conditions are necessary for at least a portion of the crop, and losses in weight and quality are high for that portion of the crop kept for the October-December period. In the North Island, the natural storage temperatures are seldom low enough to discourage sprouting once the resting period is over, with the result that it is difficult to keep potatoes in good condition after August. On the other hand cooler winter temperatures allow potatoes to be stored successfully until early October in the South Island. During the later months of the year the country as a whole is dependent upon the South Island for its supply of table potatoes, and from October to December, the quality rapidly falls.

Until recent years, attention has been devoted mainly to the physical conditions of storage, and Emilsson (1949) has reviewed the effect of various factors such as temperature and humidity upon sprouting. In general, temperature is the most important factor, high temperatures (e.g. 25° to 30°C. = 80° to 90°F.) encouraging sprouting and low temperatures (3° to 5°C. = 37° to 41°F.) discouraging sprouting. There is some evidence that tubers kept for a period at very low temperatures (0° to 1°C.) may sprout more rapidly when the temperature rises than those kept at somewhat higher temperatures (5° to 15°C.). High humidity discourages sprouting at intermediate temperatures, but appears to have little effect at low or high temperatures. From the practical point of view the best storage temperature is around 38° to 40°F., for at this temperature sprouting is inhibited almost indefinitely, while the quality does not suffer to the extent that it does at lower temperatures. It is impossible to obtain natural storage temperatures as low as this for any long period in New Zealand and, at the end of the storage period, the temperature frequently approaches the optimum for sprouting. Refrigeration is expensive and is unlikely to be an economic proposition as it would not be in use for more than three to four months of the year. Consequently, other methods of discouraging sprouting have been sought.

Work on the influence of plant hormones upon plant development led naturally to studies of the effects of various chemicals upon sprouting of potatoes. Especially important was the pioneer work of Denny (1926a, b, 1929, 1930, 1942, 1945) at the Boyce Thompson Institute in the United States. Aspects studied included the acceleration or inhibition of sprout growth, methods of application (e.g. to tubers or to the growing plants), and the residual effects upon table and seed tubers.

The main chemicals that have been used are as follows:

For breaking the dormancy of potato tubers—ethylene chlorhydrin, acetylene, thiourea.

For overcoming the dominance of apical sprouts and encouraging more sprouts to develop—thiourea.

For inhibiting sprouting—methyl ester of alphanaphthaleneacetic acid (MANA), tetrachlornitrobenzene (TCN), isopropylphenylcarbamate (IPPC), 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and maleic hydrazide (MH).

The results with sprout inhibitors have been so encouraging that all except 2,4,5-T are now used on a large scale in some countries overseas.

The experiments reported here are concerned with the effect of sprout inhibitors upon varieties of table potatoes grown in New Zealand. A subsequent paper deals with the effect upon seed potatoes.

EXPERIMENTS WITH SPROUT INHIBITORS, APPLIED AS DUSTS

1949

A small trial studied the effect of the methyl ester of alpha-naphthaleneacetic acid (MANA) upon potato tubers.

From each of three varieties of potatoes, Aucklander Short Top, Chippewa, and Dakota, harvested on 18 May, eight 50-lb. bags were prepared, graded to a uniform size. On 14 July, four bags of each variety were dusted with a commercial preparation of MANA (2.2% active ingredient) at 1 oz. per bag. The twelve dusted bags were stacked at random in one stack, and the twelve control bags in another stack alongside but separated by an impervious layer under an open sided lean-to shed. Each stack was then covered with several layers of sack sheets to keep out frost and to keep in the volatile gases. This

TABLE 1. EFFECT OF MANA UPON SPROUTING

Variety	Date	Treatment	Final Weight (lb.)	Loss (lb.)	Loss (%)	Sprouts (lb.)	Sprouts as % Final Wt.
Aucklander Short Top	20 Oct.	Control	43.2	6.8	13.6	2.6	6.1
		MANA	44.6	5.4	10.7	1.2	2.6
	8 Nov.	Control	41.4	8.6	17.2	3.2	7.7
		MANA	44.3	5.7	11.5	0.9	1.9
	13 Dec.	Control	39.1	10.9	21.8	3.0	7.7
		MANA	40.7	9.3	18.6	0.8	2.0
Chippewa	20 Oct.	Control	44.0	6.0	11.9	1.8	4.2
		MANA	45.1	4.9	9.8	0.4	0.8
	8 Nov.	Control	42.0	8.0	15.9	2.1	5.1
		MANA	43.3	6.7	13.4	0.7	1.5
	13 Dec.	Control	39.8	10.2	20.4	3.0	7.6
		MANA	41.4	8.6	17.2	1.1	2.7
Dakota Red	20 Oct.	Control	45.3	4.7	9.3	1.0	2.1
		MANA	45.9	4.1	8.3	0.3	0.6
	8 Nov.	Control	43.4	6.6	13.2	1.4	3.3
		MANA	44.2	5.8	11.5	0.5	1.1
	13 Dec.	Control	39.6	10.4	20.8	2.3	5.8
		MANA	41.2	8.8	17.6	0.9	2.3
Average for three varieties							
	20 Oct.	Control	44.2	5.8	11.6	1.8	4.1
		MANA	45.2	4.8	9.6	0.6	1.3
	8 Nov.	Control	42.3	7.7	15.4	2.2	5.3
		MANA	43.9	6.1	12.1	0.7	1.5
	13 Dec.	Control	39.5	10.5	21.0	2.8	7.0
		MANA	41.1	8.9	17.8	1.0	2.4

type of storage is not uncommon in New Zealand. One dusted bag and one control of each variety were examined on 20 October, two of each on 8 November, and the remaining one of each on 13 December. Sprouts were removed and weighed, tubers were weighed and losses calculated, and notes were taken on tuber quality.

Results

The results are given in Table 1.

Conclusions

There was a slight but consistent reduction in weight loss with treatment.

Treated tubers were greatly superior in quality to untreated. The latter were soft and partly shrivelled at the later dates of inspection.

Sprouts were long (up to 12 in.) on untreated tubers and short (0–1 in.) on treated tubers, resulting in untreated tubers having approximately three times the weight of sprouts.

Even under the poor storage conditions of the trial, MANA was quite satisfactory for keeping table potatoes in good condition well into December.

1950

Two commercial dusts containing MANA and TCN (3% active ingredient) were compared on two varieties, Dakota Red and Katahdin, in two types of storage, an open-air clamp and a barn.

One-hundred-pound bags of uniformly graded tubers were treated at recommended rates (MANA 3 lb. per ton and TCN 10 lb. per ton) on 17 August. Two bags of each variety treatment were examined on 6 October and on 24 October. Because the tubers were needed for another experiment, it was not possible to leave them beyond the latter date.

Results

The results are given in Table 2.

Conclusions

Both MANA and TCN controlled sprouting at least until the end of October.

Sprouting was rather higher in the clamp at the later date, but treatments caused significant reductions in sprouting in both types of storage.

TCN tended to have a greater effect at the first examination. Observation suggested that on these two varieties, the effect of MANA tailed off slowly while the effect of TCN came to an end rather more suddenly.

As in the previous year, there was a small but consistent reduction in weight loss with treatment, but of greater importance was the greater firmness of the treated tubers.

TABLE 2. EFFECT OF MANA AND TCN UPON SPROUTING

Variety	Date Inspected	Storage	Treatment	Final Weight (lb.)	Loss (%)	Sprouts (lb.)	Sprouts as % of Final Wt.
Dakota	6 Oct.	Barn	Control	94.1	5.8	1.0	1.1
	,,	,,	MANA	95.5	4.4	0.1	0.1
	,,	,,	TCN	95.8	4.2	0.2	0.2
	,,	Clamp	Control	91.4	8.6	1.1	1.2
	,,	,,	MANA	94.4	5.6	0.1	0.1
	,,	,,	TCN	93.9	6.1	0.2	0.2
	24 Oct.	Barn	Control	92.1	7.8	2.0	2.2
	,,	,,	MANA	94.1	5.8	0.2	0.2
	,,	,,	TCN	92.2	7.8	0.5	0.6
	,,	Clamp	Control	88.2	11.8	2.6	2.9
	,,	,,	MANA	92.8	7.2	0.9	1.0
	,,	,,	TCN	93.7	6.3	0.3	0.4
Katahdin	6 Oct.	Barn	Control	92.3	7.7	0.7	0.7
	,,	,,	MANA	94.2	5.8	0.2	0.2
	,,	,,	TCN	93.4	6.6	0.2	0.2
	,,	Clamp	Control	91.2	8.8	1.4	1.5
	,,	,,	MANA	93.9	6.0	0.1	0.1
	,,	,,	TCN	94.1	5.9	0.1	0.1
	24 Oct.	Barn	Control	89.2	10.8	2.6	2.9
	,,	,,	MANA	92.2	7.8	0.4	0.4
	,,	,,	TCN	91.7	8.3	0.9	1.0
	,,	Clamp	Control	85.2	14.8	2.9	3.4
	,,	,,	MANA	89.6	10.4	2.7	3.0
	,,	,,	TCN	91.7	8.3	1.4	1.6

1951

A commercial dust containing 2.4% isopropylphenylcarbamate was applied to two varieties, Aucklander Short Top and Dakota Red, on 2 July. Storage in a clamp and in a brick store were again compared. Samples were examined on 24 September, 30 October, and 30 November, and on each date three 25-lb. bags of each treatment and control were examined for sprouting and weight loss and the results averaged.

Results

The results are given in Table 3.

Conclusions

In untreated material, sprouting was greater with barn storage than clamp storage, probably because of the higher temperature in the barn.

In treated material, there was greater sprouting with material stored in the clamp.

In untreated material, Aucklander Short Top usually sprouted much more than Dakota, whilst in treated material Dakota sprouted more than Aucklander Short Top.

TABLE 3. EFFECT OF IPPC UPON SPROUTING OF POTATO TUBERS

Variety	Date	Treatment	Storage	Final Wt. (lb.)	Loss (%)	Sprouts (lb.)	Wt. Sprouts as % of Final Wt.
Aucklander Short Top	24.9.51	Treated	Store	23.7	5.0	0.0	0.0
		Control	„	23.4	6.3	0.3	1.4
		T	Clamp	23.8	4.7	0.0	0.0
		C	„	23.7	5.0	0.2	1.0
	30.10.51	T	Store	23.1	7.7	0.0	0.0
		C	„	21.6	13.7	1.5	6.8
		T	Clamp	23.7	5.3	0.0	0.0
		C	„	21.9	12.3	0.9	3.9
	30.11.51	T	Store	22.9	8.3	0.0	0.0
		C	„	19.6	21.7	1.9	9.7
		T	Clamp	22.8	8.7	0.1	0.3
		C	„	21.0	16.0	1.7	8.2
Dakota	24.9.51	T	Store	23.6	5.7	0.0	0.0
		C	„	23.4	6.3	0.1	0.3
		T	Clamp	24.2	3.3	0.0	0.0
		C	„	23.8	4.7	0.1	0.3
	30.10.51	T	Store	23.2	7.3	0.0	0.1
		C	„	22.4	10.3	0.5	2.1
		T	Clamp	23.7	5.3	0.1	0.5
		C	„	23.2	7.3	0.4	1.9
	30.11.51	T	Store	22.0	12.0	0.4	1.7
		C	„	20.9	16.3	1.0	4.6
		T	Clamp	22.2	11.0	0.2	0.9
		C	„	22.9	8.3	1.1	4.7

Treatment reduced sprouting to negligible proportions at least until the end of November. (Small samples kept from the trial remained firm with few sprouts until well into the new year).

In every case except one, treatment resulted in a reduction in weight loss, especially after the longer storage periods.

Treated tubers were much firmer and of better quality than untreated.

IPPC can be used to control sprouting of potato tubers, and it appears to be more effective upon Aucklander Short Top than Dakota.

General Conclusions

All three tuber dusts controlled sprouting to a marked degree with a consequent improvement in the quality of the stored potatoes. All were satisfactory in the early storage period, but TCN seemed to persist for a shorter time than the other two, while IPPC gave the most

prolonged response and appeared to induce almost permanent dormancy in the variety Aucklander Short Top, some tubers of which were kept until March without sprouting. It is likely that there will be differential responses from other varieties to the three dusts as was found by Downie (1950, 1952).

EFFECT OF FOLIAGE SPRAYS UPON TUBER DORMANCY

1949

The sodium salt of 2,4,5-trichlorophenoyxacetic acid was applied in water at 100 gal. per acre in four concentrations, 0, 50 ppm., 100 ppm., 200 ppm., to the foliage of three varieties, Aucklander Short Top, Chippewa, and Dakota Red, at three stages of growth:

Aucklander Short Top and Chippewa in full flower, Dakota Red at early flowering stage, 23 December.

Dakota in full flower, other varieties beginning to mature, 20 January.

Dakota growing vigorously, the other two varieties rapidly maturing 30 January.

Growth was very good in spring, but dry weather in the summer made the earlier varieties, Aucklander Short Top and Chippewa, mature early (yield about 5 tons per acre). On the other hand Dakota survived the dry spell and continued growth in March when rain fell (yield 11–12 tons per acre). The highest concentration of spray made Dakota cease flowering in a few days and gave the foliage a more mature look. The effect was progressively less with lower concentrations and with later applications. Chippewa was slightly affected in a similar way, but there was no obvious effect upon the foliage of Aucklander Short Top.

The trial was harvested on 18 May, the tubers graded and weighed, and the table and seed sizes stored until 9 November when the sprouts were removed and the tubers and sprouts weighed.

Results

The results are given in Tables 4–7.

Conclusions

There was a tendency towards higher yields with a low concentration of 2,4,5-T, but in every variety treatment combination the higher concentration reduced yield.

There was a slight but consistent increase in dormancy with increase in concentration of 2,4,5-T.

The greatest effect was obtained from the first spraying (pre- to early flowering). There was little effect upon the variety Aucklander Short Top even at the early spraying, probably because the spraying was too late for this early-maturing variety.

Only at the highest concentration was the reduction in sprouting sufficiently large to be of any value. At this concentration there was a considerable amount of cracking in the tubers, sufficient to make the line unsaleable.

TABLE 4. EFFECT OF 2,4,5-T UPON YIELD AND TUBER DORMANCY

Date Treated	Variety	2,4,5-T (p.p.m.)	Plot Yield (lb.) Table + Seed	Wt. after Storage (lb.)	Loss (lb.)	Loss (%)	Sprouts (lb.)	Wt. Sprouts as % of Final Wt.
23.12.48	Aucklander Short Top	0	23.5	18.4	5.1	21.7	2.0	10.8
		50	28.9	25.1	3.7	12.8	1.6	6.2
		100	26.3	21.5	4.8	18.2	1.9	8.8
		200	23.2	18.9	4.3	18.6	1.1	5.7
	Chippewa	0	29.8	25.6	4.2	13.9	1.6	6.2
		50	34.7	29.9	4.8	13.7	2.0	6.5
		100	29.3	24.3	5.0	17.1	1.2	5.0
		200	29.5	26.4	3.1	10.4	0.4	1.5
	Dakota	0	46.1	41.0	5.1	11.1	1.5	3.8
		50	45.3	40.9	4.4	9.7	1.1	2.6
		100	56.2	49.6	6.6	11.7	0.9	1.8
		200	35.6	32.1	3.5	9.9	0.6	1.8
20.1.49	Aucklander Short Top	0	26.5	22.0	4.5	16.9	1.6	7.2
		50	21.9	17.4	4.5	20.5	1.7	9.7
		100	17.1	13.4	3.7	21.5	1.1	8.0
		200	15.9	13.2	2.7	16.9	1.1	8.3
	Chippewa	0	21.6	18.1	3.5	16.2	1.2	6.7
		50	25.1	21.9	3.2	12.6	1.3	5.8
		100	19.7	16.7	3.0	15.0	0.9	5.1
		200	18.8	16.1	2.7	14.6	0.6	4.0
	Dakota	0	39.0	35.0	4.0	10.2	1.0	3.0
		50	32.6	28.7	3.9	12.0	0.4	1.4
		100	45.6	40.7	4.9	10.9	1.2	2.9
		200	38.7	35.1	3.6	9.3	0.8	2.4
30.1.49	Aucklander Short Top	0	17.2	12.4	4.8	27.8	1.2	9.3
		50	19.7	14.3	5.4	27.5	1.9	13.1
		100	23.2	16.4	6.8	29.4	1.9	11.7
		200	18.0	13.1	4.9	27.3	1.8	13.9
	Chippewa	0	20.3	16.3	4.0	19.6	1.4	8.4
		50	16.3	13.6	2.7	16.7	0.7	5.1
		100	19.1	15.2	3.9	20.3	1.1	7.2
		200	16.5	14.2	2.3	13.7	0.6	4.5
	Dakota	0	40.6	35.1	5.5	13.6	1.2	3.5
		50	45.9	41.2	4.8	10.4	1.1	2.7
		100	37.1	32.7	4.4	11.9	0.8	2.5
		200	34.3	30.1	4.1	12.1	0.4	1.4

There was no consistent reduction in weight loss during storage with treatment.

The results from the trial were not sufficiently promising to suggest further work nor to recommend the use of 2,4,5-T as a foliage spray to control sprouting. These results were in accordance with those of Smith *et al.* (1949).

TABLE 5. AVERAGE OF THREE SPRAYINGS ACCORDING TO VARIETIES

Variety	Treatment	Yield Table + Seed (lb.)	Wt. After Storage (lb.)	Loss (lb.)	Loss %	Sprouts (lb.)	Sprouts as % of Final Wt.
Aucklander Short Top	1	22.4	17.6	4.8	21.9	1.6	9.0
	2	23.5	19.0	4.5	19.3	1.7	9.0
	3	22.2	17.1	5.1	23.0	1.6	9.5
	4	19.0	15.1	4.0	20.8	1.3	8.8
Chippewa	1	23.9	20.0	3.9	16.2	1.4	7.0
	2	25.4	21.8	3.5	14.0	1.3	6.0
	3	22.7	18.8	3.9	17.4	1.1	5.6
	4	21.6	18.9	2.7	12.5	0.6	2.9
Dakota	1	41.9	37.0	4.9	11.6	1.3	3.4
	2	41.3	36.9	4.4	10.6	0.9	3.3
	3	46.3	41.0	5.3	11.5	1.0	2.4
	4	36.2	32.4	3.8	10.4	0.6	1.9

TABLE 6. AVERAGE OF THREE VARIETIES ACCORDING TO SPRAYING DATES

23.12.48	1	33.2	28.3	4.8	14.5	1.7	6.0
	2	36.3	32.0	4.3	11.8	1.5	4.8
	3	37.3	31.8	5.5	14.7	1.3	4.2
	4	29.4	25.8	3.6	12.4	0.7	2.7
20.1.49	1	29.0	25.0	4.0	13.7	1.3	5.1
	2	26.5	22.7	3.9	14.5	1.1	5.0
	3	27.5	23.6	3.9	14.1	1.0	4.4
	4	24.5	21.5	3.0	12.3	0.9	4.0
30.1.49	1	26.0	21.3	4.8	18.3	1.2	5.9
	2	27.3	23.0	4.3	15.7	1.2	5.3
	3	26.5	21.4	5.0	19.0	1.3	5.9
	4	22.9	19.1	3.8	16.4	1.0	5.0

TABLE 7. AVERAGE OF 3 VARIETIES AND THREE SPRAYINGS

	1	29.4	24.9	4.5	15.4	1.4	5.7
	2	30.1	25.9	4.2	13.8	1.3	5.0
	3	30.4	25.6	4.8	15.8	1.2	4.7
	4	25.6	22.1	3.5	13.6	0.8	3.8

EFFECT OF SPROUT INHIBITORS UPON THE DRY-MATTER AND ASCORBIC-ACID CONTENT OF POTATO TUBERS

Trial 1

Material from the 1949 trial treated with MANA was removed from storage on 8 November, and tested for dry matter content and ascorbic acid content on 9 November.

TABLE 8. Effect of MANA upon the Dry-matter and Ascorbic-acid Content of Potato Tubers

Variety	Treatment	D.M. %	Ascorbic Acid mg.% wet wt.	Ascorbic Acid mg.% dry wt.
A.S.T.	MANA	23.3	11.2	47.7
	Control	24.5	11.1	45.2
Chippewa	MANA	24.5	9.9	40.3
	Control	23.4	10.0	43.2
Dakota	MANA	25.7	11.1	43.2
	Control	27.3	11.7	43.0
Average 3 vars.	MANA	24.5	10.7	43.8
	Control	25.1	11.0	43.6

There were no significant differences.

Trial 2

Tubers of the variety Aucklander Short Top were supplied by the Department of Agriculture, Christchurch, from a storage trial comparing MANA with TCN. Tests for ascorbic-acid and dry-matter content were made on 10 August and 7 November 1949.

TABLE 9. Effect of MANA and TCN upon Dry Matter and Ascorbic Acid

Treatment	10 August 1949			7 November 1949		
	D.M. %	A.A. mg.% wet wt.	A.A. mg.% dry wt.	D.M. %	A.A. mg.% wet wt.	A.A. mg.% dry wt.
Control	23.1	17.8	76.9	22.1	11.4	51.5
MANA	23.1	18.5	80.0	23.8	11.8	49.9
TCN	23.3	18.5	79.3	26.2	11.6	44.3

There were no significant differences.

Conclusions

No treatment appeared to alter either dry-matter or ascorbic-acid content. However, TCN delayed sprouting longer than MANA and this appears to be reflected in a higher dry-matter content at the later testing period. Measured on a dry-matter basis there is a tendency for the ascorbic-acid content to be higher at the later date with the most heavily sprouted material. This is analagous with the increase found by Allison and Driver (1953) with all varieties at the end of the storage period.

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STUDIES ON HORTICULTURAL FORMULATIONS OF STREPTOMYCIN

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Summary

Three formulations and a crude preparation of streptomycin sulphate were all highly effective in preventing infection of peach leaves by *Pseudomonas syringae,* when applied as sprays at 100 and 50 μg./ml., streptomycin before inoculation. At a concentration of 10 μg./ml., disease control varied in tests on 3 different occasions, but all preparations except streptomycin sulphate were significantly effective in each test.

When peach seedlings were sprayed at a concentration of 100 μg./ml., left in a glasshouse for 3 days, and then washed to remove surface deposits, infection was reduced at the 1% level of significance, by all formulations up to 11 days after washing. Streptospray and Agrimycin reduced infection up to 18 days after washing.

Following admixture with a number of fungicides and insecticides, there was no reduction in effectiveness of any streptomycin preparation in preventing *Ps. syringae* infection of Golden Queen peach seedlings.

Observations for phytotoxicity on stone and pip fruit varieties were made on orchard trees following sprays applied during bloom and during periods of rapid growth in spring. When phytotoxicity occurred, it was most severe with colloidal streptomycin. There was little observable damage with either Agrimycin or streptomycin sulphate at the concentrations investigated.

INTRODUCTION

There are now numerous publications reporting the successful use of streptomycin as a prophylactic agent for many plant diseases caused by bacteria (Zaumeyer 1956).

In New Zealand, streptomycin is very effective in preventing development of blast of stone fruit caused by *Ps. syringae* (Dye, D. W. 1953, 1954, 1956a; Dye and Dye 1954a, 1954b).

This paper reports results of investigations of the effectiveness of several horticultural formulations of streptomycin in preventing infection of peach seedlings by *Ps. syringae.* The phytotoxicity of these formulations to common fruit-tree species and their compatibility with several fungicides and insecticides is also reported.

MATERIALS

Streptomycin preparations:

1. Crude streptomycin sulphate containing 342 units/mg.*
2. Streptospray: A liquid concentrate containing 132,000 units/ml. streptomycin, plus a wetting agent.*
3. Agrimycin 100: 15% streptomycin and 1.5% oxytetracycline (terramycin) in powder form.†

* Supplied by Glaxo Laboratories (N.Z.) Ltd., Palmerston North.

† Supplied by Chas. Pfizer & Co. Inc., Brooklyn 6, New York, U.S.A.

4. Colloidal streptomycin: A lipoid-soluble formulation of streptomycin plus a wetting agent.* When mixed with water the streptomycin forms a colloidal suspension.

Fungicides and insecticides:

1. Flit 406: A wettable powder containing 50% Captan, N-(trichloromethylthio)-4-cyclohexene-1, 2-dicarboximide.
2. Thirospray: A wettable powder containing 50% thiram, bis (dimethylthiocarbamoyl) disulphide.
3. Bordeaux mixture: Prepared from Te Papapa copper sulphate of 98–99% purity and Hyndlym hydrated lime containing not less than 95% calcium hydroxide.
4. Micronizer D.D.D.: A wettable powder containing 25% D.D.D. dichlorodiphenyl dichloroethane.
5. Nexa: A wettable powder containing 16% lindane, γ-1, 2, 3, 4, 5, 6-hexachlorocyclohexane.
6. Lawry's lime sulphur: An aqueous solution containing 15% calcium polysulphides.
7. Colsul 40: A paste containing 40% colloidal sulphur.

General Methods

Golden Queen peach seedlings raised in pots in a glasshouse, were inoculated with *Ps. syringae* as previously described (Dye and Dye 1954a), except that leaves were inoculated in place of stems. During disease development, plants were placed in a cabinet maintained at 16 ± 2°c., with a water-saturated atmosphere and with natural lighting. Infection was recorded 6 days after inoculation by recording the number and diameter of lesions that developed at inoculation sites. The same strain of *Ps. syringae* was used throughout. All streytomycin concentrations are expressed as streytomycin base. Check plants were sprayed with water.

Effectiveness of Streptomycin Formulations in Preventing Infection of Peach Foliage by *Ps. syringae*

Five plants were sprayed with aqueous solutions or suspensions of each formulation at 100, 50, and 10 μg/ml. streptomycin. Each formulation was included in an experiment at each concentration, but tests at different concentrations were carried out on different occasions. Leaves were inoculated as soon as dry after spraying. During the interval between spraying and inoculating, plants were held in a room without temperature or humidity control, and the time required for plants to dry varied by several hours. Methods of spraying and inoculation were approximately uniform in all experiments.

The only preparation with good leaf-wetting properties was the colloidal formulation. At a concentration of 100 μg./ml., this preparation formed a thin complete film over leaf surfaces. At the same concentration, Streptospray wetted foliage slightly better than streptomycin sulphate, Agrimycin, or water, but did not form a complete film. Leaf-infection results are recorded in Table 1,

TABLE 1. *Ps. syringae* INFECTION OF PEACH FOLIAGE SPRAYED WITH STREPTOMYCIN FORMULATIONS

Concentration streptomycin μg./ml.	100	50	10	10	10	10 Average
Date exp. started	3/12/54	28/1/55	11/2/55	27/10/55	2/12/55	
	% Inoculation Sites Infected by *Ps. syringae**					
Check	78	96	92	84	76	84
Strep. sulphate	10	13	11	81	32	41
Streptospray	3	5	9	60	36	35
Colloidal strep.	—	4	7	39	28	25
Agrimycin	9	7	4	41	17	24
	Means of Equivalent Angles					
Check	64.0	86.0	75.6	70.2	61.8	69.2
Strep. sulphate	16.7	21.0	15.6	65.2	33.0	37.9
Streptospray	4.3	9.8	16.8	54.0	35.6	35.5
Colloidal strep.	—	5.4	11.8	38.4	31.0	27.1
Agrimycin	14.5	13.6	8.8	39.6	21.0	23.1
Differences 5%	7.8	8.5	9.4	12.7	12.0	9.3
for significance 1%	10.5	11.4	12.6	16.9	16.0	12.3
	Average Diameter of Infected Areas (mm.)					
Check	5.4	10.3	7.6	5.8	4.7	6.0
Strep. sulphate	2.4	2.1	6.2	4.3	4.0	4.8
Streptospray	2.0	2.0	5.0	3.5	3.7	4.1
Colloidal strep.	—	1.6	4.7	3.2	2.7	3.5
Agrimycin	2.2	1.9	6.0	3.0	2.9	4.0

* 2 inoculation sites on each of 10 leaves on each of 5 plants.

At 100 and 50 μg./ml., all treatments were highly effective in preventing blast development. At 10 μg./ml., disease control varied considerably on different occasions even though infection on check plants remained approximately constant. In the first experiment (11 February 1955) all formulations were approximately as effective as at 100 and 50 μg./ml. In subsequent tests at 10 μg./ml. (27 October and 2 December), this concentration was much less effective. Nevertheless, all preparations except crude streptomycin sulphate significantly reduced infection in all tests at 10 μg./ml.

PERSISTENCE OF STREPTOMYCIN ACTIVITY IN PEACH FOLIAGE

It is known (Dye, M. H. 1956) that streptomycin enters peach foliage from aqueous sprays of streptomycin sulphate. The effect of formulation on leaf penetration and on persistence of activity in leaves was therefore investigated.

Plants received one spray only, at a concentration of 100 μg./ml. streptomycin, and were then placed in a glasshouse. After 3 days the foliage was washed by immersion in running water for 4 minutes. During

the 3-day absorption periods, the glasshouse temperature was 21 ± 5°c. and humidity 78 ± 19%. Plants that had been left in the glasshouse for 1, 2, and 3 weeks after spraying (i.e. 4, 11, and 18 days after washing) were inoculated on the same occasion by making 4 needle punctures on 12 leaves of each plant and spraying these leaves with a broth culture of *Ps. syringae*. Other leaves from the same plants were used to detect antibacterial activity by bioassay. Four 5-mm. diameter discs were cut from each of 2 to 6 leaves from each plant. These discs were placed on the surface of plates seeded with a spore suspension of *Bacillus subtilis* A.T.C.C. 6633, in Difco streptomycin assay agar. Growth of the test organism surrounding the leaf discs was inhibited when antibacterial activity was present.

The experiment was performed twice, involving 4 plants in each treatment in both tests.

TABLE 2. PERSISTENCE OF ANTIBACTERIAL ACTIVITY IN PEACH LEAVES WASHED 3 DAYS AFTER SPRAYING WITH STREPTOMYCIN FORMULATIONS*

	Plant Infection Results								
	% Inoculation sites Infected by *Ps. syringae* **			Analysis on Equivalent Angles			Average Diameter of Infected Areas (mm)		
Weeks after spraying	1	2	3	1	2	3	1	2	3
Check	73.5	89.3	90.7	67.9	73.7	73.1	4.5	5.0	4.4
Strep. sulphate	30.8	43.7	65.7	32.9	40.5	56.7	1.2	1.9	3.1
Streptospray	20.3	36.1	43.3	25.4	36.5	38.9	0.9	1.4	2.0
Colloidal strep.	53.7	60.2	71.9	46.6	51.9	59.7	2.4	2.2	3.1
Agrimycin	40.6	52.3	60.1	38.9	46.4	51.6	1.7	2.0	2.8
Differences for significance 5%					14.6			1.2	
Differences for significance 1%					19.4			1.6	

	Bioassay Results					
	% Leaf Discs with Activity †			Means of Equivalent Angles		
Check	0	0	0	0	0	0
Strep. sulphate	19.6	11.5	10.4	20.9	13.2	13.4
Streptospray	31.1	30.5	18.7	29.8	35.1	20.4
Colloidal strep.	30.4	26.1	39.6	30.5	25.6	38.5
Agrimycin	20.8	12.5	8.3	21.1	13.7	8.6
Differences for significance 5%				11.6	14.2	20.0
Differences for significance 1%				15.3	18.7	26.5

* Plants received 1 spray at a concentration of 100 μg/ml., streptomycin.

** Each figure is the mean of 48 inoculations on each of 8 plants.

† Each figure is the mean of 8–24 leaf-disc samples from each of 8 plants.

Results are given in Table 2. Infection was reduced at the 1% level of significance by all formulations up to 2 weeks after spraying, and by Streptospray and Agrimycin up to 3 weeks after spraying. Bioassay and plant-infection results were in agreement in that antibacterial activity was detected by both methods in all streptomycin treatments. With 3 of the 4 formulations the number of leaf-disc samples with antibacterial activity decreased as plant infection increased. This suggests that disease control was directly related to the presence of an antibacterial substance. In plants treated with the colloidal formulation, relatively poor disease control was associated with a relatively high percentage of leaf-disc samples with antibacterial activity.

Of the 4 preparations, streptomycin was in a water-soluble form in streptomycin sulphate, Streptospray, and Agrimycin. The colloidal formulation contained streptomycin with low aqueous solubility.

It was previously reported (Dye, M. H. 1956) that all detectable streptomycin sulphate on peach-leaf surfaces could be removed by washing. If this applied to other water-soluble forms of streptomycin, the activity detected would have been within the leaves. With the colloidal formulation, washing has less effect in removing surface activity, and this may account for the relatively high proportion of leaf discs which showed antibacterial activity. Since the water-soluble forms were superior to the colloidal preparation in disease control, the activity of the latter formulation was probably largely confined to leaf surfaces.

Compatibility with Fungicides and Insecticides

The effectiveness of the formulations in preventing infection of peach seedlings by *Ps. syringae* when applied as sprays in combination with selected fungicides and insecticides was investigated. All materials were prepared separately as aqueous solutions or suspensions at twice the final concentration. Equal volumes of 2 preparations were then mixed. The foliage was inoculated with *Ps. syringae* as soon as leaves were dry after spraying. Experiments with different fungicides or insecticides were on different occasions. Each streytomycin preparation was included alone and in combination with a fungicide or insecticide in each experiment. Final spray concentrations were as follows: All streytomycin preparations, 100 μg./ml. streptomycin; Flit 406, 1 lb./100 gal.; Thirospray, 2 lb./100 gal.; Bordeaux mixture, 1:2:100; D.D.D., 2 lb./100 gal.; Nexa, 1½ lb./100 gal.; Lime sulphur, ½ gal., plus Colsul 40, 2 lb./100 gal.

Results are recorded in Table 3.

All streptomycin preparations applied either alone or combined with the fungicides or insecticides were highly effective. Infection in all treatments containing streptomycin was too low to carry out analyses on equivalent angles, except in the experiment with lime sulphur and colloidal sulphur. Disease in plants sprayed with fungicides or insecticides alone was not significantly different from that in check plants, except with Bordeaux mixture and Thirospray.

Leaf damage consisting of chlorotic or necrotic spots was observed on plants sprayed with Bordeaux mixture and lime sulphur plus colloidal sulphur, when applied either alone or mixed with streptomycin preparations. In further tests under the same conditions, plant damage

TABLE 3. *Ps. syringae* INFECTION OF PEACH FOLIAGE FOLLOWING SPRAYS COMBINING STREPTOMYCIN FORMULATIONS WITH SOME FUNGICIDES AND INSECTICIDES

	% Inoculation Sites Infected by *Ps. syringae**												Means of Equivalent Angles	
Experiment Number	1		2		3		4		5		6		6	
	Alone	Flit 406 1 lb./100 gal.	Alone	Thirospray 2 lb./100 gal.	Alone	Bordeaux mixture 1:2:100	Alone	D.D.D. 2 lb./100 gal.	Alone	Nexa 1½ lb./100 gal.	Alone	Lime sulphur Colloidal sulphur ½ gal./2 lb./100 gal.	Alone	Lime sulphur Colloidal sulphur ½ gal./2 lb./100 gal.
Water	65	—	89	—	53	—	65	—	62	—	71	—	59	—
Streptomycin sulphate	0	0	0	0	1	0	6	0	0	0	6	15	11	20
Streptospray	0	0	1	1	5	0	7	0	0	1	2	5	4	11
Agrimycin	0	2	0	1	0	0	2	0	0	0	6	2	7	5
Colloidal strep.	0	1	0	1	1	0	0	4	0	0	1	4	3	9
Alone	—	53	—	53†	—	11†	—	54	—	72	—	84	—	67
Differences for significance 5%														13
1%														17

* 2 inoculation sites on each of 10 leaves on each of 5 plants.

Footnote:—All streptomycin formulations applied at a concentration of 100 μg./ml., streptomycin.

† significantly less infection than in water check at 1%.

was produced by lime sulphur, but not by colloidal sulphur when applied either alone or mixed with streptomycin. No plant damage was caused by any streptomycin formulation applied either alone or mixed with the fungicides or insecticides, except where damage was caused by the fungicide or insecticide alone.

TOXICITY TO STONE- AND PIP-FRUIT TREES

Observations for toxic reactions in apricot, cherry, peach, and plum varieties under orchard conditions at Alexandra, and in apple and pear varieties at Nelson, were made in 1955–56. One spray was applied during bloom for observations on damage to flowers and effect on fruit set. A further spray was applied during rapid growth in spring to observe the effect on foliage. With each formulation, three concentrations (100, 250, and 500 μg./ml.) of streptomycin were each applied to three branches of the varieties listed in Table 4. All formulations at any one concentration were included on the same tree. Replicates were on the same or different trees. Check branches on each tree received no treatment. Tests during the blossom period were on branch areas each bearing approximately 50 blooms or bloom clusters.

TABLE 4.—Toxicity of Streptomycin Formulations to Fruit Trees

	Streptomycin Sulphate									Streptospray						Agrimycin						Colloidal Streptomycin								
	Concentration Streptomycin (μg./ml.)																													
	100			250			500			100			250			500			100			250			500			100		
	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.	FL.	FR.	L.
Moorpark apricot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oullins apricot	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0
Roxburgh Red apricot	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0
Twyford cherry	0	–	0	0	–	0	0	–	SL.	0	–	0	SL.	–	0	M	–	SL.	0	–	0	0	–	0	0	–	SL.	M	–	0	S	–	0	S	–	SL.
Yellow Magnum plum	0	–	0	SL.	–	0	M	–	0	SL.	–	0	M	–	0	S	–	0	0	–	0	SL.	–	0	M	–	0	S	–	0	S	–	0	S	–	0
Muir peach	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blackboy peach	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	S	0	S	S	0
Winter Cole pear	0	0	0	0	SL.	0	0	SL.	0	0	S	0	0	S	0	0	S	0	0	0	0	0	0	0	0	SL.	0	S	S	SL.	S	S	M	S	S	M
Jonathan apple	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	SL.	0	–	0	0	–	0	0	–	0	0	–	0	SL.	–	0	M	–	M
Sturmer apple	0	–	0	0	–	0	0	–	0	0	–	0	0	–	0	0	–	SL.	0	–	0	0	–	0	0	–	0	0	–	0	SL.	–	SL.	M	–	M

FL = flower damage; FR = reduction in fruit set; L = leaf damage;
O = no damage; SL. = slight; M = moderate; S = severe; — = not determined.

Observations for flower and leaf damage and estimates of the amount of premature petal fall and fruit set were made approximately 2, 7, and 28 days after spraying. Phytotoxicity recorded as slight was of doubtful practical significance.

A summary of the results appears in Table 4.

When toxic reactions occurred, they were most severe in the colloidal streptomycin treatments. There was little observable damage with either Agrimycin or streptomycin sulphate at the concentrations investigated. No toxic reactions were observed in Muir peach or in Moorpark, Oullin's, and Roxburgh Red apricot. Petal burn and premature petal fall occurred in Twyford cherry at all concentrations of the colloidal formulation and at the higher concentrations of Streptospray. On Yellow Magnum plum, all formulations caused petal burn and in some instances premature petal fall. Reduced fruit set followed applications of Streptospray and colloidal streptomycin to Winter Cole pear during bloom.

At Alexandra, the effect on fruit set in many varieties was not determined because of poor fruit set on check branches due to frost.

Toxic reactions in leaves were seldom observed with streptomycin sulphate, Streptospray, and Agrimycin, and when they did occur were not severe. With Twyford cherries, all the formulations caused slight marginal chlorosis of developing leaves when sprayed at 500 μg./ml. during bloom. The effect was transitory. No effect was observed on mature leaves. Streptospray at 500 μg./ml. caused a similar marginal chlorosis on developing leaves on Jonathan and Sturmer apples. Toxic reactions were more frequently observed with the colloidal formulation and were of a different type. A percentage of young leaves and shoots of Winter Cole pears and Jonathan and Sturmer apples became scorched and turned black following sprays with this formulation.

FRUIT SET ON PEAR TREES SPRAYED DURING BLOOM

Results of field trials to control blast of pear with streptomycin were reported by Dye, D. W. (1956b). Crude streptomycin sulphate, applied 3 times during bloom at a concentration of 100 μg./ml. streptomycin, reduced blossom infection without increasing the yield of harvested fruit. The present paper reports reduced fruit set following a single application of Streptospray to Winter Cole pears during bloom in 1955–56 (Table 4). Further field experiments to determine the effect of spraying pear trees with streptomycin during the flowering period were carried out in 1956–57.

Tests were on Winter Cole pear trees in the same orchard at Nelson as those used for observations on toxic reactions the previous season, and on William's Bon Chretien pear trees at Havelock North. Infection by *Ps. syringae* was not observed in the test trees. The two commercially available formulations, Agrimycin and Streptospray, were applied at 100 and 250 μg./ml. total antibiotic and streptomycin content respectively. Branch areas bearing 50 to 100 flower clusters were sprayed on 3 occasions, namely, at open cluster, full bloom, and petal fall. All treatments were included on each tree. Check branches on each tree were sprayed with water. Six replicates were on the same or different trees. Fruit was counted on the trees on two occasions and again when harvested. Results are recorded in Table 5.

TABLE 5. FRUIT SET ON PEAR TREES AFTER SPRAYING WITH STREPTOMYCIN FORMULATIONS DURING BLOOM *

	Mean Percentage of Fruit (as % of original blossom clusters)					
	Variety Winter Cole growing at Nelson			Variety William's Bon Chretien growing at Havelock North		
	Date counted			Date counted		
	30/10/56	24/12/56	27/3/57 (Harvested)	30/10/56	26/11/56	8/2/57 (Harvested)
Check (water)	46	42	41	53	21	21
Agrimycin 100 μg./ml.	37	35	34	60	21	19
Agrimycin 250 μg./ml.	49	44	44	53	14	14
Streptospray 100 μg./ml.	48	43	43	59	20	20
Streptospray 250 μg./ml.	32	32	32	50	22	20
L.S.D. between treatments 5%		20		29	12	
L.S.D. between treatments 1%				40	17	
L.S.D. between times 5%		20			22	
L.S.D. between times 1%					30	

*Trees were sprayed on 3 occasions, viz., open cluster, full bloom, and petal fall.

Neither Agrimycin nor Streptospray reduced fruit set in either variety.

DISCUSSION

It was reported (Dye, M. H. 1956) that streptomycin enters peach foliage following aqueous sprays, and that climatic conditions affect the rate and degree of penetration.

Variation in disease control on different occasions by sprays containing 10 μg./ml. streptomycin (Table 1) has now been observed on numerous occasions. Differences in leaf penetration might be responsible for these results. During the interval between spraying and inoculating, climatic conditions were not controlled, and the rate at which the sprays dried varied by several hours. An effect of variation in leaf penetration would be more likely to be observed at minimal concentrations.

Physiological differences between plants used on different occasions might also be responsible for the variations in disease control obtained at 10 μg./ml. This could occur even though there was little variation in infection on check plants in the different experiments. Hemphill and Goodman (1955) reported increased fire-blight control in apple trees by the addition of plant-growth-regulating substances to mixtures of streptomycin and terramycin, and concluded that their results were not due to an effect of growth-regulating substances on the pathogen

per se, or on the antibiotics, but to host-plant reaction to plant-growth regulators.

In the compatibility tests (Table 3), both Thirospray and Bordeaux mixture significantly reduced infection by *Ps. syringae* when used alone. When Bordeaux mixture was added to the streptomycin formulations, no infection occurred. Combinations of Bordeaux mixture and streptomycin may have an added or even a synergistic effect which was not determined in the present work because infection in the streptomycin treatment alone was negligible.

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BLOAT IN CATTLE ON RED CLOVER

III. TREATMENT AND PREVENTION WITH ANTI-FOAMING AGENTS

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Summary

Bloat in cows on red clover has been successfully treated with anti-foaming agents, including vegetable oils (peanut, raw linseed, soya-bean and olive), vegetable turpentine, emulsified tallow, whale oil, cream, lanoline, five liquid paraffins, and two paraffin-wax emulsions. Anti-foaming agents giving variable results were a ricinoleic acid derivative, silicone preparations, detergents, and diethyl ether. Glycerol proved ineffective.

Treatments without anti-foaming action failed to give relief. These included sal volatile, adrenaline, mepyramine maleate, sodium bicarbonate, ferric chloride, sodium thiosulphate, and a preparation containing acetotrimethylcolchicinic acid.

The vegetable oils were shown to be equally as effective as turpentine without the disadvantage of irritancy. The minimum effective dose of the vegetable oils, whale oil, vegetable turpentine, and liquid paraffins, was found to be below 50 ml. while that of emulsified tallow was approximately 30 g.

The requirements of an agent for use as a remedy in the field are discussed. The agents with the most desirable properties appear to be peanut oil and emulsified tallow. Dose rates of 120 ml. (4 fl. oz.) of the oil or 90 g. of tallow are suggested.

Bloat was prevented by the administration of anti-foaming agents before feeding. However, protection lasted only for the feed following treatment, and except for greatly increasing the dose, no method of administration was found that would ensure protection at a subsequent feed.

When bloat was prevented, intake of potent herbage was as high as that of safe herbage, without detectable ill-effects, except in the case of very light paraffins.

A limited number of cases of bloat on short-rotation (H1) ryegrass have been successfully treated with vegetable oils which were also found effective in preventing bloat on this feed.

The mechanism of action of anti-foaming agents is discussed, also the limitations of these substances in the treatment of field cases of bloat.

Introduction

It was demonstrated in Part I (Johns, 1954) that bloat in cattle fed on red clover is primarily due to a foaming of the rumen ingesta and not to any direct toxic action on the animal. The effect of this foaming is the retention within the ingesta of a proportion of the fermentation gases which cannot therefore be eliminated by eructation. A preliminary report was given which indicated that bloat on red clover could be effectively treated with or prevented by a variety of substances having the common property of acting as anti-foaming agents.

The study of bloat is complicated by the interaction of both plant and animal factors, and their apparent independent variation makes

the carrying out of controlled experiments a difficult matter. Throughout the present investigations every effort has been made to obtain quantitative data. This has been facilitated by the use of stall-fed identical-twin cows and by the use of the tympanograph.

This paper gives further details of the results of the experiments in the treatment and prevention of red-clover bloat reported in Part I (covering the period summer–autumn 1954) together with results obtained during the two subsequent seasons, 1954–55 and 1955–56.

Methods

Details of the feed, the feeding regime, and the grading system for assessing bloat were given in Part I; and of the tympanograph and its use in Part II (Reid, 1957a). Two sets of identical twins and one other cow were used during the first season. Three further sets of twins were added during the second season.

The criterion of effectiveness of an agent in relieving bloated animals was the deflation time. This is the interval between dosing and the complete disappearance of all traces of bloat as detected by palpation of the left flank. Although substantial relief, as indicated by the disappearance of distress, occurs before all retained gas is freed, the deflation time provides a conservative measure with a well defined end-point.

New treatments were usually first tried out on moderately bloated cows. A negative result was indicated by the animal's continuing to bloat with increasing severity so that relief by an effective treatment was necessary. This technique, illustrated in Fig. 2 (glycerol; Anthisan), allowed negative results to be obtained without complications due to natural deflation and without danger to a valuable animal. Trials with severely bloated animals were carried out only if preliminary experiments were successful. In doubtful cases, confirmation of the effectiveness of a treatment was often given by the performance of the material as a prophylactic.

In order to have adequately controlled tests of the effectiveness of agents in relieving bloated animals, the aim was to have in any one experiment three untreated cows (including the twin of the treated cow). Under ideal conditions, these cows would remain at their maximum bloat grading (varying from II to IV) for a period of more than 60 min. and then deflate slowly over a further 60–120 min. Although such circumstances occurred frequently during periods of severe bloating, at other times fewer bloated animals were available and natural deflation was more rapid. Negative results, whether of treatment or prophylaxis, were, of course, self-controlled. Because of the complication of natural deflation, negative results were considered more reliable than positive results.

No more than two animals were recorded with the tympanograph during any one feeding period. These were usually one of each of two twin sets, so that recording of two treatments could be made simultaneously.

Drenches were made up with water to a final volume of approximately 600 ml. Those containing substances immiscible with water were shaken up vigorously immediately before administration.

A list of the materials tested for their bloat-relieving and preventive properties is given below together with their source of supply.

The vegetable oils (raw linseed, olive, peanut, soya-bean) and vegetable turpentine. These were all high-grade products available commercially.

Avlinox. A polyethylene glycol derivative of ricinoleic acid. This proprietary remedy for bloat was supplied by the manufacturers, Imperial Chemical Industries Ltd.

Whale oil, New Zealand crude, supplied by W. & R. Fletcher (N.Z.) Ltd.

Emulsified tallow A. Mixed ruminant tallow emulsified with soap and glyceryl monostearate. Prepared by W. & R. Fletcher (N.Z.) Ltd.

Emulsified tallow B. Mixed ruminant tallow (20%) and light liquid paraffin (10%) emulsified with glyceryl monostearate. Prepared by Vacuum Oil Co. (N.Z.) Ltd.

A range of paraffins supplied by The Vacuum Oil Co. (N.Z.) Ltd.
Ceremul A. A 47–52% paraffin-wax emulsion with a non-ionic emulsifier.
Ceremul C. A 41–46% wax emulsion with a soap-type emulsifier.
Heavy liquid paraffin B.P. (white oil 890).
Light liquid paraffin B.P. (S 1020).
Odourless kerosene (EF471W).
Stanvac Odourless Solvent. An isoparaffin fraction of low volatility.

An isoparaffin used in horticultural sprays (Soltrol 170) supplied by The Fruitgrowers Chemicals Co. Ltd.

Silfro. A proprietary remedy for bloat, containing 4.2% methyl and phenyl polysiloxanes and 1.2% bornyl acetate in liquid paraffin, prepared by Walter Gregory and Co. Ltd., Somerset, England.

D.C. Antifoam A. A semi-solid polymerized dimethyl silicone manufactured by the Dow Corning Corporation U.S.A. Supplied by Swift & Co. Ltd., Wellington, N.Z.

D.C. Antifoam A.F. A water-dispersible form of D.C. Antifoam A, same source.

Emulsion of D.C. Antifoam A in liquid paraffin. Prepared by Premier Products Ltd., Wellington, N.Z.

Lissapol N. An alkylated phenol ethylene oxide manufactured by Imperial Chemical Industries Ltd.

40E and 80E. Detergents marketed and supplied by the Vacuum Oil Co. (N.Z.) Ltd. containing respectively 40% and 80% of sodium dodecyl benzyl sulphonate.

Anthisan. Mepyramine maleate manufactured by May & Baker Co. Ltd., England.

Nudame. A proprietary remedy for bloat containing 0.00075% W/V acetotrimethylcolchicinic acid (colchiceine), manufactured by The

Crown Chemical Co., Kent, England. The sample was supplied by Messrs. McDermott and Duncan Ltd., Wellington, N.Z.

Miscellaneous. Cream, butter, hydrated lanoline, ethyl ether, sodium bicarbonate, glycerol, sal volatile, ferric chloride, sodium thiosulphate.

Results

Treatment of Bloated Cows by Drenching

The large number of agents tested for their effectiveness in relieving bloated animals have been divided, on the results obtained, into three groups—1, Effective; 2, Unreliable; 3, Ineffective. The results will be presented under these headings.

Effective Agents

Vegetable Oils. When 100 ml. of raw linseed oil was given on four occasions to severely bloated cows, girth changes occurred as illustrated in Fig. 1a. In one instance (curve 4) rapid deflation commenced immediately after drenching, while on two other occasions (curves 1 and 2) a lag period of 5 to 8 min. was evident. The fourth drenching (curve 3) resulted in an immediate slow deflation for some 30 min. followed by a rapid deflation. These curves are typical of those obtained with vegetable oils. Raw linseed, olive, peanut, and soya-bean oils were given as drenches of 50 to 300 ml. They never failed to give relief. In an experiment involving 58 drenchings, little difference in deflation times was found between oils or between dose rates (Table 2). From the records illustrated in Fig. 1a and many others it appears that deflation times are governed at least in part by the initial lag phase. Once this phase is past deflation rates are rapid and relatively constant.

A characteristic feature of treatment with vegetable oils was that, after the subsidence of bloat, the girth usually continued to decrease leading to a marked hollowing of the animal's flanks. The animal would usually resume eating before deflation was complete.

Turpentine. In Fig. 1b, records of girth changes following the administration of vegetable turpentine illustrate the slower deflation rate obtained compared with that following vegetable oils. Hollowing of the flanks was not observed. The irritant action was marked and intake was depressed during the next feed.

Animal Oils and Fats. Those tested include crude whale oil, emulsified tallow preparations, cream, butter, and lanoline (for average deflation times see Table 2). Girth changes after treatments with whale oil and emulsified tallow were similar to those following vegetable oils (Fig. 1c, d.). Long deflation times were again associated with a prolonged lag phase (curve 1, Fig. 1d). Hollowing of the flanks always occurred after whale oil and after higher dose rates of tallow. Feeding was usually resumed during deflation, though larger doses of crude whale oil (600 ml.) tended to depress appetite.

In an attempt to improve the physical properties, and particularly the stability, of tallow emulsion, a mixed emulsion was prepared containing 20% tallow and 10% light liquid paraffin B.P. in water with a glyceryl monostearate emulsifier. This proved effective. Cream

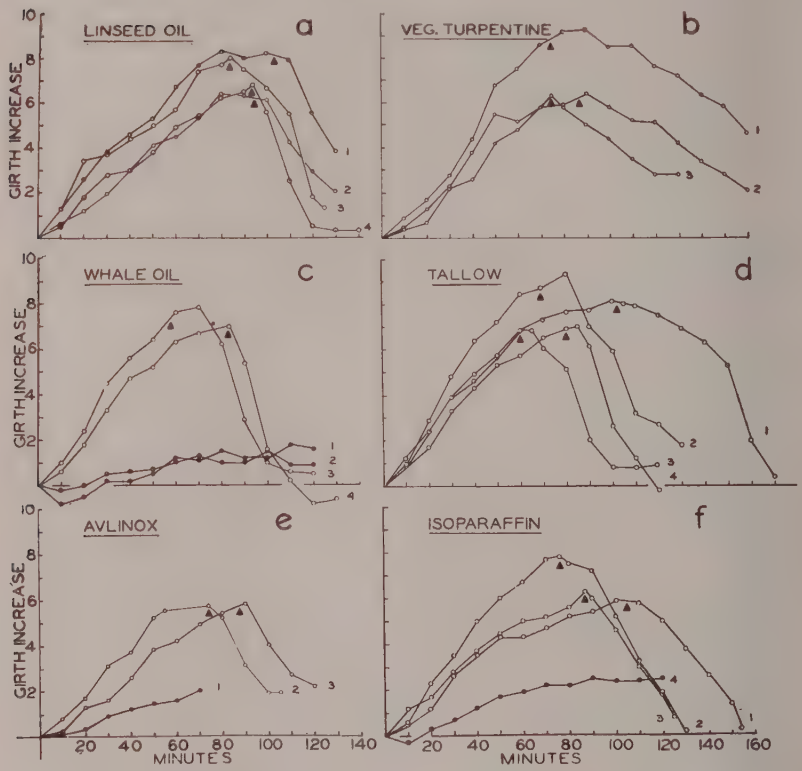

Fig. 1.—Effective treatments for bloat. Time in minutes from start of feeding; drenches given at ▲ ; bloat grading at drenching in roman numerals.
(a) 1 and 2, III; 3 and 4, III–IV, all 100 ml.
(b) 1 and 2, 100 ml.; 3, 50 ml.; all III.
(c) 1 and 2, 250 ml. before feeding; 3 and 4, 100 ml.; III.
(d) 1, 3.3 g., IV; 2, 50 g., IV; 3 and 4, 67 g., III.
(e) 1, 15 ml. before feeding potent clover; 2 and 3, 15 ml., III.
(f) 1, 50 ml., IV; 2 and 3, 100 ml., III; 4, 100 ml. before feeding potent clover.

proved effective, as did butter and hydrated lanoline. Both the latter materials were difficult to handle and no further work was done with them.

Avlinox. This was administered at the recommended dose rate (10–15 ml.) and showed girth changes similar to those following oils and tallow (Fig. 1e). Hollowing of the flanks after deflation however was not observed. Deflation times appeared to be independent of dose, though there was an apparent correlation between deflation time and severity of bloat (Table 2). There was one apparent failure.

Mineral Oils and Waxes. A range of paraffins was used as listed above. In preliminary experiments, heavy liquid paraffin was found to be as effective as the vegetable oils. The lighter paraffins were tried in the hope that their lower viscosity and greater spreading

power, particularly in the case of the isoparaffin types, would enable them to penetrate more readily through the rumen contents, hence hastening deflation. No such effect could be detected (Table 2).

Girth changes following administration of liquid paraffins again closely resembled those after vegetable oils (Fig. 1f). Feeding was often resumed during the deflation period. However, with the lighter paraffins (EF471W, and the isoparaffin types) intake during the following feed was depressed (Reid, 1957b).

Continued administration of liquid paraffins is known to depress the absorption of a number of fat-soluble vitamins. As it was considered unlikely that waxes would dissolve significant amounts of the vitamins concerned, the two wax emulsions were tried in the hope that they would be effective without having this undesirable side effect. However, although both preparations relieved bloat, they did not compare favourably in deflation times with the vegetable oils (Table 2).

Unreliable Agents

Silicones. A number of silicone preparations was tried. Though effective in relieving bloat in some instances, complete failures to deflate the treated animal more rapidly than its untreated twin were frequently encountered. Among the silicones used were Silfro and two preparations containing Dow Corning Antifoam A.

Silfro, used at the recommended dose of 1 fl. oz., deflated in 20 min. a cow bloated to Grade III. The rapidity of this deflation may have been partly due to the paraffin vehicle. No further material was available for additional experiments.

A water-dispersable 30% emulsion of Dow Corning Antifoam A (D.C. Antifoam AF) was tried on ten occasions in doses (calculated as silicone) ranging from 0.17 to 3.4 g. Its performance was most erratic. When doses of 0.17 and 0.42 g. were given to moderately bloated cows, deflation took place in 28 and 26 min. respectively. However, in six cases where 1.0 g. was given to cows bloated to various degrees between II and IV, there was one complete failure and the results in the remaining cases were inconclusive.

In those doubtful cases when 3.0–3.4 g. were administered, a partial deflation occurred over 30–60 min. Following this, deflation ceased, with the cow remaining mildly bloated for a further 30–60 min. An oil drench given at this stage resulted in a rapid deflation typical of the use of this material. This is well illustrated in Fig. 2 when a drench of D.C. Antifoam AF (1 g. silicone) given at A was followed by a second drench of 2 g. silicone at B in an attempt to increase the deflation rate. After a further 50 min. the girth started to increase again and a dose of 50 ml. of soya-bean oil resulted in rapid deflation followed by hollowing of the flanks.

In these trials, two samples of D.C. Antifoam A.F. from separate manufacturing batches were used. In a later investigation material from a third batch used as a prophylactic also gave irregular results. Hence it seems unlikely that the inconsistency in our trials was due to an inactive batch of silicone.

An emulsion of D.C. Antifoam A in liquid paraffin was tried in two field cases at a dose rate of 1 g. silicone. One animal, bloated to

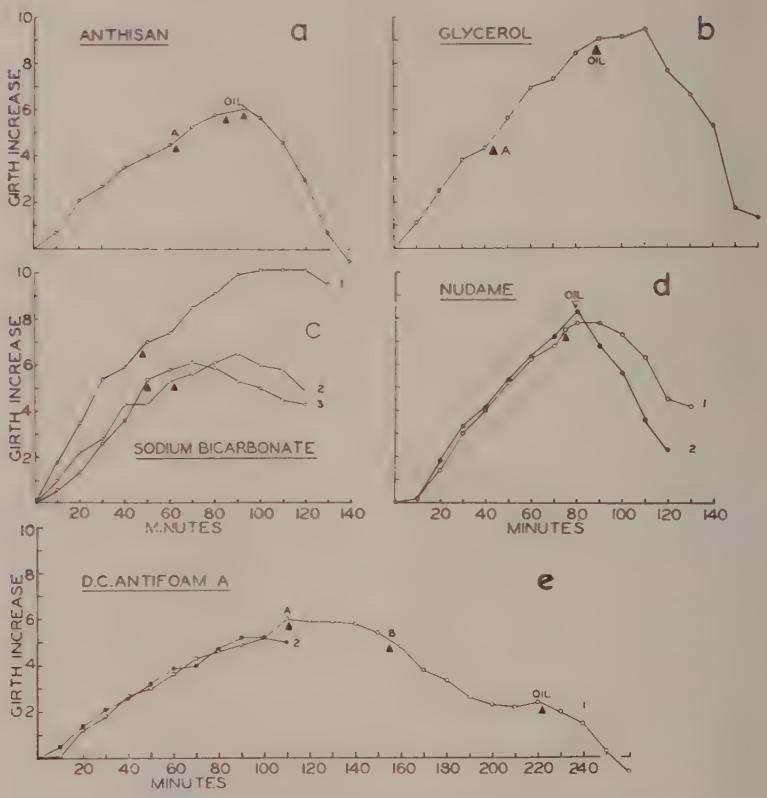

Fig. 2.—Ineffective and unreliable treatments.

(a) 25 ml. at A, III; 50 ml. and 250 ml. olive oil at IV.

(b) 250 ml. at A, II; 100 ml. soya-bean oil at IV.

(c) 1, 100 g., IV; 2, 100 g., III; 3, 200 g., III.

(d) 1, 1 fl. oz. Cow bloated to III then slowly deflated; 2, 1 fl. oz. before feeding. Cow bloated to III, when 100 ml. peanut oil was immediately effective.

(e) 1, 1 g. at A, IV; 2 g. at B, III; cow still bloated at 210 min. when 50 ml. of soya-bean oil gave deflation; 2, 5 g. given with 1.5 lb. dry feed before feeding on potent clover, cow bloated to III.

Grade III at the time of treatment, deflated slowly over more than 70 min. A second animal bloated to Grade II, remained unchanged in condition for 45 min. and was still mildly bloated after 70 min. In contrast, a peanut-oil drench given at the same time deflated a third cow in 30 min.

Several other highly surface-active silicones were tried alone and with dispersing agents but none was found that gave positive results consistently.

Detergents. Three commercial detergents, Lissapol N, 40E, and 80E were tested,

Lissapol N was given on three occasions. Doses of 5 and 10 ml. produced inconclusive results while one of 45 ml. took 32 min. to deflate a cow bloated to Grade II.

More extensive trials were made with the preparations containing sodium dodecyl benzyl sulphonate. The detergent 40E has been used as a remedy for bloat in the field. Successful results have been claimed for a dose of 25 g. (10 g. of surface-active agent). In the present investigation, the results with this and the stronger 80E were highly erratic (Table 1). Even with doses of surface-active agent as high as 20 g. there was marked variation in effectiveness. At all the dose rates used, some of the longest deflation times followed administration to only moderately or mildly bloated animals. It appeared that some variable factor, possibly the final concentration in the rumen, was limiting the effectiveness of the agent. Even when conditions appeared optimal, however, the detergent did not compare favourably with the various oils as a bloat remedy (Table 2).

TABLE 1. TREATMENT OF BLOATED COWS WITH SODIUM DODECYL BENZYL SULPHONATE

Material	Dose of Detergent*	Cow	Bloat Grade when Treated	Deflation Time (min.)
40E Sample 1	5 g.	1	II–III	(unchanged in 50 min.)
	„	2	II–III	(to I in 135 min.)
	„	262	III	110
	10 g.	128	II–III	(to I–II in 45 mins.)
	„	128	II	(to I in 96 min.)
	„	127	II	60
	„	128	III	(to I–II in 70 min.)
	20 g.	2	II	90
40E Sample 2	10 g.	90	II–III	49
	„	262	II	46
	„	1	III	40
	„	89	III–IV	85
	„	90	III–IV	95
	„	128	III	(to I in 75 min.)
80E	20 g.	89	II–III	50
	„	294	I	65
	„	89	II–III	37
	„	90	II	62
	„	90	III	59
	„	89	III	36
	„	293	II	35

* Expressed as sodium dodecyl benzyl sulphonate.

Summary of Effective and Unreliable Agents

The results of experiments with the various agents as outlined above are summarized in Table 2.

It will be seen that none of the vegetable oils differed significantly in their deflation times and do not differ from tallow or whale oil.

TABLE 2. MEAN DEFLATION TIMES OF BLOATED ANIMALS FOLLOWING TREATMENT WITH EFFECTIVE AND UNRELIABLE AGENTS

Treatment	No. of Trials	Mean Deflation Time (min.)
1. Raw linseed oil	14	32.2 ± 2.2
2. Olive oil	8	34.6 ± 4.4
3. Peanut oil	37	32.9 ± 1.9
4. Soyabean oil	7	30.0 ± 4.7
5. Vegetable turpentine	6	54.0 ± 10.0
6. Avlinox (Grade III bloat)	5	31.0 ± 1.7
Avlinox (Grade IV bloat)	5	61.0 ± 6.2
7. Whale oil	11	35.5 ± 5.0
8. Emul. tallow	34	35.4 ± 2.2
9. Cream	5	42.0 ± 4.8
10. Ceremul A.	5	50.4 ± 8.4
11. Ceremul C.	3	49.7 ± 3.5
12. Heavy liquid paraffin BP	2	(25, 31)
13. Light liquid paraffin BP	6	37.7 ± 3.9
14. Odourless kerosene	1	(44)
15. Stanvac odourless solvent	8	39.9 ± 5.0
16. Soltrol 170	4	36.0 ± 3.7
17. Antifoam A*	10	(26, 28)
18. 40E (detergent)†	14	71.9 ± 9.3
19. 80E (detergent)	7	50.6 ± 5.2
All vegetable oils	66	32.7 ± 1.3
All Avlinox	10	46.0 ± 5.8
All Ceremul	8	50.1 ± 5.1
40E + 80E	21	61.9 ± 6.0

* 8 failures
† 6 failures

The wax emulsions and detergents (figures do not include failures) are inferior to the vegetable oils while the isoparaffins are obviously not superior.

The deflation times for Avlinox differ significantly when administered at Grade II and Grade IV bloat. The difference between 40E and 80E was significant at the 10% level.

It appears that of all the agents tried the vegetable oils, whale oil, and tallow, have the lowest deflation time and are most consistent in their effect.

Ineffective Agents

Irritants and Stimulants. It is commonly believed that some form of paralysis of the rumen musculature plays a central part in the pathogenesis of bloat, and remedies used in the field have included various irritants, stimulants, or specific antidotes to presumed paralytic agents. In our investigations no material relying on such actions alone was found to relieve bloated cows. The strong irritant, vegetable turpentine (Fig. 3, curve 2), found to be effective in relieving bloated animals, has anti-foaming activity as well as irritancy (Clark 1948).

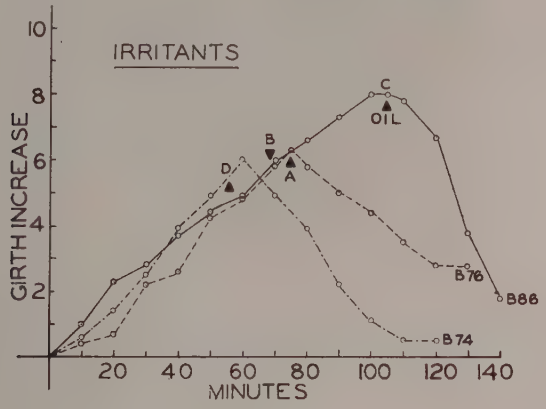

Fig. 3.—Irritants.

1. (B 86) Sal volatile (irritant) 80 ml. at B, II–III, animal continued to bloat IV, 100 ml. linseed oil at C gave relief.
2. (B 76) Vegetable turpentine (irritant, antifoaming) 50 ml. at A, II–III gave relief.
3. (B 74) Linseed oil (non-irritant, antifoaming) 50 ml. at D, II–III.

An irritant commonly used in mixtures with linseed oil is sal volatile (aromatic solution of ammonia, Brit. Vet. Codex). Since the oil alone has been found effective it was of interest to determine whether the sal volatile played any part in causing deflation. The irritant was given in doses of 80 and 100 ml. to two bloated cows without effect (Fig. 3, curve 1). The animal continued to bloat after dosing until relief was rapidly obtained with 100 ml. of linseed oil given subsequently. In Fig. 3, curve 3, illustrating the immediate relief given by 50 ml. of oil alone, is included for comparison. Irritancy is clearly not necessary as a property of successful agents for uncomplicated frothy bloat.

Details of experiments with adrenaline and with the antihistaminic, Anthisan, both of which proved ineffective, have been given in Part I (Johns, 1954). An unsuccessful attempt to relieve bloat with 25 ml. of Anthisan and the subsequent success of an olive oil drench is illustrated by a record of girth changes in Fig. 2d.

An intramuscular injection of a Carbachol solution (3 mg. of carbamylcholine chloride) failed to relieve a moderately bloated cow, which became seriously bloated 30 min. later. Relief was given in 17 min. by an emulsified tallow drench containing 125 g. of tallow.

Nudame was used on four occasions at the recommended dose rates of ½–1 fl. oz. When administered to three bloated cows (Grade II–III, there was one failure (dose ½ oz.) while in the other two cases (½ oz. and 1 oz.) deflation took approximately 50 min. (Fig. 4d, curve 1). On a fourth occasion, a bloated cow (Grade II–III) took 68 min. to deflate after a 1 oz. dose of Nudame. Pre-feed treatment with 1 oz. failed to protect an animal from bloat, which was then promptly relieved by 100 ml. of peanut oil (Fig. 2d, curve 2).

Miscellaneous. Sodium bicarbonate has been commonly used in drenches for bloated cows. It was used on five occasions during the present investigations in doses of 100 or 200 g. As illustrated in Fig. 2c, the treatment was ineffective. In two out of the five cases evidence of marked hyperpnoea was seen in the tympanograph tracings. It was to be expected that the use of bicarbonate would place a further strain on the animal, for at the pH of rumen contents in bloat (pH 6.2 and below, unpublished results) carbon dioxide will be rapidly evolved, thereby increasing intra-ruminal pressure (curve 1, Fig. 2c) and further embarrassing the already impaired respiration.

Drenches containing ethyl ether (10 ml.), ferric chloride (50 g.), or sodium thiosulphate (60–120 g.) proved ineffective. A 250 g. dose of glycerol given to a cow at Grade II bloat was ineffective and, as illustrated in Fig. 2b, the animal continued to bloat to Grade IV. It was successfully treated with a drench of 100 ml. of soya-bean oil.

Water (1.5–3.0 l.) used as a drench before or after feeding in bloating and non-bloating cows had no effect either on the production of bloat or on existing bloat. Clearly the water used in the preparation of drenches (400–600 ml.) was an inactive vehicle.

Prevention of Bloat with Anti-foaming Agents

After the value of anti-foaming agents in the relief of bloated animals had been demonstrated, the use of these substances in preventing the ailment was explored. It was found that administration of any of the vegetable oils, whale oil, emulsified tallow, the various liquid paraffins, or Avlinox to cows before their feeding on potent red clover did in fact protect the animals from bloating, but only for a limited time. Dose rates as low as 50 ml. of the oils, 30 g. of tallow, or 10 ml. of Avlinox were found effective. Various methods of administration were used.

Drenching

When a cow was drenched with an effective anti-foaming agent immediately before feeding, the flanks became hollow and remained so for the whole 2-hr. feeding period. This is shown in Fig. 4a. Curve 5 shows the girth changes in cow 128 following drenching with 100 ml. of peanut oil immediately prior to feeding. Despite the animal's having eaten 6.9 lb. D.M. of red clover, its girth at the end of the feeding period was less than before drenching. The control animals during this experiment bloated severely. Similar flat tympanograph tracings following drenching of animals with 250 ml. and 750 ml. of the oil just before feeding are shown in curves 3 and 4.

In contrast to the three recordings listed above, when an interval of 30–40 min. had elapsed between treatment with the oil and the start

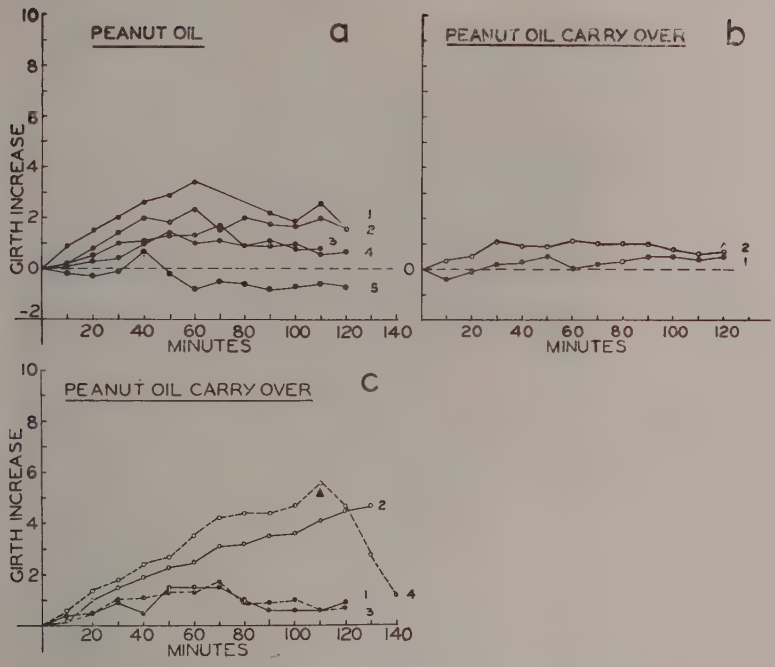

Fig. 4.—Peanut oil before feeding on potent clover.

(a) Girth changes for feed following treatment with oil. Curves 1, 2, and 4, 250 ml.; 3, 750 ml.; 5, 100 ml. 1 and 2, 30–40 min. between drenching and feeding; 4 and 5, less than 5 min.

(b) Persistence of effect of large dose of oil. 750 ml. oil fed with 400 g. lucerne chaff. 1, a.m. feed; 2, p.m. feed showing carry over of effect.

(c) Persistence of effect of oil drench and oil absorbed on carrier. 1, 250 ml. oil soaked on to 400 g. lucerne chaff fed to cow 294 at morning feed. 3, twin mate 293 drenched 250 ml. oil. In the afternoon cow 293, curve 4, bloated and deflated with 50 ml. oil; cow 294, curve 2, bloated.

of feeding, curves such as 1 and 2 (both 250 ml.) resulted. Although the animal (294 was used on both occasions) was completely protected from bloat, a marked increase in girth occurred equivalent to that normally seen in untreated non-bloating cows. The relationship of the interval between treatment and feeding to the subsequent girth increase was observed on many occasions and suggested that the oil was rapidly lost from the rumen.

This hypothesis was confirmed by the fact that although oil drenching never failed to protect an animal fed potent clover within 3 hr. of drenching, little protection remained at a subsequent feed, even at doses of 250 ml. (Fig. 4c, curves 3, 4). However, the effects of a drench of 750 ml. of undiluted peanut oil given before the morning feed were carried over to the afternoon feed. When treatments were given prior to the afternoon feed, in no case did protection persist overnight.

The effects of pre-feed treatments with several other agents are shown in Fig. 1c, e, and f.

Oils Absorbed on Carriers

In an attempt to reduce the rate of loss of oils from the rumen, the possibility was explored of absorbing the oil on inert carriers, whence it would be slowly released. Activated carbon and diatomaceous earth were both unsatisfactory absorbents but flour appeared to be suitable. A usable drench was prepared by mixing 200 ml. of oil with 200 g. of flour, leaving the mixture to soak for a short time, and then diluting it with 800 ml. of water. The result of using this mixture on a 30-cow milking herd was disappointing. Administration of the drench at the morning milking did not reduce the incidence of bloat during the afternoon.

Similar results were obtained when vegetable oils or whale oil were mixed with dairy ration, bran, lucerne, chaff, or sawdust, and fed to the stalled animals before offering them red clover. Protection from bloat was achieved for the immediate feeding period, but at doses of up to 250 ml. of oil, this protection was substantially lost before the afternoon feeding. Girth-change curves from a typical experiment are shown in Fig. 4c. Cow 294 was fed 250 ml. of peanut oil soaked on 300 g. of lucerne chaff, before the morning feed, while its twin, 293, was drenched with the same quantity of oil. Typical flat records (curves 1 and 3) were obtained from both animals in the morning. During the afternoon feed both cows bloated, the curve for 293 (4) showing a slightly more rapid rate of girth increase than that for 294 (2). At the point marked, 293 was drenched again with 50 ml. of peanut oil, and deflated in 30 min. The difference in rate of girth increase between curves 2 and 4, as if there were some residual effect from the oil-carrier, was seen on a number of occasions when this experiment was repeated, using different animals. A definite residual effect was obtained when 750 ml. of peanut oil was given on 400 g. of lucerne chaff before the morning feed. Not only was the experimental animal normal in the afternoon when the two control animals were graded III–IV and IV, but the girth-change record of the afternoon feed was almost as flat as that seen in the morning (Fig. 4b). This level of dosage is not economic from a farming view point and would have serious effects on milk quality.

The Effects of Treatment and Prevention of Bloat on Feed Intake

The reduction of food intake caused by bloating has already been described in Part I (Johns, 1954). When mildly or moderately bloated cows were drenched with oils or tallow, they usually recommenced eating as soon as bloat had disappeared, or even before this. When bloat had been severe, however, resumption of feeding was usually delayed much longer.

When bloating was prevented by pre-feed treatment, cows ate to capacity on potent clover and their intake was as much as twice that of bloating control animals. Thus, in one experiment, two animals were drenched with 100 ml. of soya-bean oil and 100 ml. of heavy liquid paraffin respectively before the morning feed. These cows ate 9.6 lb. and 9.3 lb. D.M. of red clover herbage and did not bloat,

whereas the three control animals all bloated to grade IV and ate 4.8, 6.3, and 6.8 lb.

The effect of bloating and of oil treatments on the intake of red clover by one animal (294) on four different occasions is shown in Fig. 5. Curve A represents a morning intake of non-bloating clover, while B represents the intake on an occasion when the animal was allowed to bloat to grade IV; this intake is half that in A. On the third occasion (curve C), a drench of linseed oil (50 ml.) was given when the animal was bloated to grade II; after rapid deflation, the animal recommenced feeding. On the fourth occasion, when 250 ml. of peanut oil was given before feeding on potent clover, the feed-intake was approximately the same as in the non-bloating, untreated animal (curve D). The corresponding girth-change curves are given in Part II (Reid, 1957a).

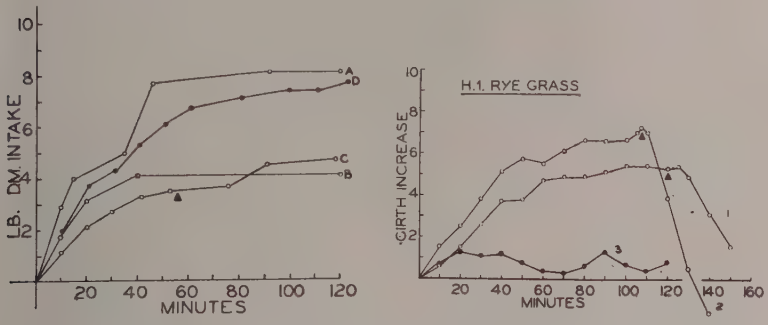

Fig. 5.—Effect of bloating, treatment, and prevention of bloat on the intake of cow 294 (4 occasions).
A. D.M. intake on non-bloating red clover (D.M. = 19%).
B. D.M. intake on potent red clover (D.M. = 21.4%).
C. As B, with relief from Grade II bloat at ▲ with 50 ml. raw linseed oil. Animal resumed eating.
D. Animal fed potent clover after pre-feed drench of 250 ml. of peanut oil.

Fig. 6.—Treatment and prevention of bloat on short-rotation (H1) ryegrass.
1, 100 ml. peanut oil, II; 2, 100 ml. raw linseed oil, III; 3, 250 ml. peanut oil before feeding potent grass.

DISCUSSION

The Use of Anti-foaming Agents in the Treatment of Clover Bloat

The results presented in this paper confirm and extend the conclusion reached by a number of previous investigators, that legume bloat is primarily a problem of foaming (McCandlish, 1937; Olson, 1942; Quin, 1943; Clark, 1948, 1950; Quin *et al.*, 1949; Weiss, 1953; Johns, 1954; Ferguson and Terry, 1955; Hungate *et al.*, 1955).

Substances with foam-breaking properties have long been used successfully in the field as bloat remedies. They have been used alone or in mixtures, and have included turpentine, vegetable oils (particularly linseed), milk, melted lard, mineral oils and paraffins, kerosene, alcohol, phenol, coal-tar derivatives, and many others. Richard Peters wrote in 1807, on the treatment of hoven cattle, "Another in the first stage

frequently successful remedy, and always useful as an auxillary after the more prompt methods before recommended is *drenching*". For this purpose he recommended "sweet oil, raw linseed, or even train oil or melted hog's lard" (quoted by Beddows, 1952). Certain anti-foaming agents have often been used because of some other property they may possess. For instance, linseed oil and milk have frequently been added to mixtures as demulcents for more irritant ingredients, e.g. turpentine (Greig and Boddy, 1942; Baker, 1954), in quantities that would undoubtedly be effective if given alone. Turpentine, phenol, and coal-tar derivatives have been given as anti-fermentatives, and alcohol as a stimulant.

The use of these agents would appear to have been largely empirical, with no knowledge of their mode of action. Since 1948, however, when Clark (1948) demonstrated that the effectiveness of several commonly used remedies, including turpentine and phenol, was not due to anti-fermentative properties, but to anti-foaming properties, attention has been given to anti-foaming agents as such. The ricinoleic acid derivative Avlinox, an anti-foaming agent of low toxicity originally used in the dyeing industry (Siotol), has been found effective (Clark, 1950; Harrow, personal communication); various silicone preparations have been experimented with (Marston, 1953; Quin *et al.*, 1949; Dougherty and Meredith, 1954; Hungate *et al.*, 1955); while Nichols (1954), Ferguson and Terry (1955) and Barrentine (1957) have investigated the use of detergents.

In the present investigation, an attempt has been made to obtain quantitative data on the effectiveness of a range of anti-foaming agents as treatments for bloated cows. In no case was a treatment effective which did not have anti-foaming action. Fourteen oily or fatty substances with foam-breaking properties never failed to give relief on the 200-odd occasions that they were used.

Treatment with Avlinox, silicone preparations, detergents, and ethyl ether gave variable results, and one, glycerol, failed altogether. Both the detergents and glycerol have well defined concentration optima for anti-foaming action, and under different circumstances both may in fact become foaming agents. They are unlikely therefore to be reliable remedies. Ferguson and Terry (1955), and Barrentine (1957), also found detergents ineffective in their experiments. The failure in the case of Avlinox was almost certainly due to underdosing; it is probable that the recommended dose should be higher than 15 ml. for severe cases. Silicones have been used in the field as bloat remedies with varying success. In a series of 155 cases treated with two silicone preparations (unfortunately, together with collateral treatment), Quin *et al.* had 25.8% failures and Barrentine (1957) found them unreliable.

The most spectacular results produced by effective anti-foaming agents followed their administration to an animal before feeding potent red clover. There was never the slightest suspicion of bloat, and, in all ways, the animal behaved perfectly normally. Here again silicones do not appear as reliable as the oils. In trying to prevent bloat, Hungate *et al.* (1955) gave 20 g. of methyl silicone and protected only 7 out of 10 steers during the grazing period following the administration of the silicone, whereas such a large dose should have given 100% protection.

The Possible Mode of Action of some Foaming and Anti-foaming Agents in Bloat

In view of the evidence of the frothy nature of red clover bloat, a brief discussion of the mode of action of foaming and anti-foaming agents appears warranted.

The foaming power of a compound in aqueous solution is chiefly determined by the magnitude of the surface tension of the solution and the mechanical and cohesive properties of the stabilizing film formed. There are two broad groups of foaming materials:

(a) Solutions of soaps and detergents in which the surface tension is usually low (about 25 dynes/cm.). This is the major factor to which soaps owe their foaming properties, although the molecular cohesion in the absorbed layer which depends upon the structure and packing of the stabilizing molecule is also important. In general, these foams are not particularly stable; they are non-viscous.

(b) Protein and saponin solutions which exhibit strong superficial viscosity and in which the surface-tension factor is subordinate to the mechanical and cohesive properties of the stabilizing film. These solutions yield foams of great stability and at the same time exhibit high surface-tension values which show little correlation with foam stability. Soaps may lower the surface tension 40–50 dynes, whereas proteins rarely lower it by more than 20 dynes/cm.

These surface-non-viscous and surface-viscous types of foam are mutually incompatible. If a soap and a saponin solution are mixed, the soap solution having the lower surface tension causes the displacement of the saponin from the surface layer, and lacking the other requisite of sufficient cohesion in the absorbed film, it yields an unstable foam. As was shown in the Results section and as has been shown by Nichols (1954) detergents can be de-bloating agents. This would appear to be evidence that the foaming agent is of the protein or saponin type which can be displaced by the detergent with greater surface activity. Again, this type of treatment for bloat is not new, as Beddows (1952) quotes from the writings of Thomas Wedge (1794) "For swelling in clover—two oz. of Castile soap and one of dialthea is strongly recommended as a remedy to prevent the necessity of tapping . . ."

Pankhurst (1941) in a study of soap films compared the oleates with the ricinoleates and showed that the introduction of the polar groups into the middle of the hydrocarbon chain (as in ricinoleates) reduced the foaming power without greatly affecting the surface tension. This is no doubt due to the fact that the increase in surface area occupied by each ricinoleate molecule leads to a loss of cohesion. "Avlinox" as a ricinoleic acid derivative would therefore be expected to be a better de-foaming agent for the viscous type of foam than the soaps or detergents. This was indeed found to be the case in the present studies.

Another group of anti-foaming agents are those which are insoluble or nearly so, such as oils and the silicones. Their effects are variable with respect to surface tension and the mode of action appears to depend on the physical properties of the particular agent used. In industry,

many foam preventives of this type have been employed, such as petroleum, fat, milk, peanut oil, and vegetable oils, while recently a great many synthetic anti-foaming agents have been used. However, our knowledge of foam breaking does not appear to have reached the stage where it can be predicted that a particular anti-foaming agent is most suitable for a particular situation. In the case of frothy bloat, it appears that of this class of insoluble anti-foaming agents the oils and fats are satisfactory for alleviating bloat. Unfortunately, for preventing the ailment, their lack of solubility and low specific gravity means that they are rapidly lost from the rumen. The lack of reliability in bloat control of such powerful anti-foaming agents as the silicones was unexpected. Failure to disperse through the rumen may be a factor contributing to their lack of effectiveness.

The Choice of Anti-foaming Agents for Field Use

Although reliability is the primary requisite of any field treatment for bloat, other factors must also be considered. It is desirable that the treatment should (a) not adversely affect the health or appetite of the animal, (b) have no deleterious effect on milk production or the quality of the milk and butterfat, (c) be inexpensive.

Cost alone would seem to limit the use of Avlinox and the silicones even if a reliable preparation of the latter were to be found.

The paraffin oils cause a number of side effects of varying importance (Goodman and Gilman, 1955). Besides passing through the gut undigested and having a laxative effect, they are to some extent absorbed and may set up irritation in the wall of the gut (Stryker 1941). Reid (1957b) has found that light paraffins markedly depress the appetite of cows, while McDowall, McGillivray, and Reid (1957) have shown that continued use of heavy paraffins interferes with the absorption of carotene and the fat-soluble vitamins.

On the evidence presented, the use of turpentine seems unjustified. Further, it is a toxic substance with a marked cumulative effect from small doses. It depresses the appetite and causes a strong taint which may appear in the milk within a few minutes of administration.

The bland vegetable oils have negligible toxicity and have the added value of being digested. There are, however, reports that corn oil and soya-bean oil depress butterfat production (Allen and Fitch, 1941; Hale and King, 1955). Also, because of their absorption into the blood stream, the vegetable fats affect the properties of the butterfat and body fat (Hilditch, 1949).

Investigations of the effects of whale oil, vegetable oils, and emulsified tallow, on the yield, flavour, and quality of milk and butterfat, have been carried out, and will be reported in subsequent papers of this series. The adverse effects of whale oil make it quite unsuitable. At high dose rates, peanut, raw linseed, and soya-bean oils had some undesirable effects, but at the dose rates recommended for treatment the effects from peanut oil were negligible. Emulsified tallow produced no adverse effects.

Of the substances tried, the most suitable for the control of bloat in the field would appear to be peanut oil and tallow.

Effectiveness of Anti-foaming Agents as Remedies for Bloat

The value of anti-foaming agents in the treatment of bloat in the field will depend on the proportion of cases that are due to foaming. Little direct information on the latter point is available, but undoubtedly frothy bloat is widespread. Clarke (1948) believes that most cases in South Africa are partly or wholly of this type. Barrentine (pers. comm.) from Mississippi found that, in every case in which the type of bloat could be determined, it was of the frothy type. In New Zealand, the successful use of anti-foaming agents in pasture spraying to control bloat indicates that the great majority of cases here are also of this type (Reid, 1955).

The efficiency of a foam-breaking agent will obviously depend on the stability of the foam itself. On some occasions, such stable foams may be formed that oils will not be effective. This appears to be the case in "feedlot" bloat (Lindahl *et al.*, 1957).

It is obvious, too, that an anti-foaming agent must reach the foam to have effect.

It is possible that portions of the drench may bypass the rumen through closure of the oesphageal groove, although this reflex is usually considered to be lost in the adult animal (see, however, Reid 1957b).

Dispersion of the agent through the rumen of a bloated cow presents difficulties. The foam is not in a simple compact body, but is intimately mixed through the rumen ingesta, although at times there may be greater concentrations in certain regions. However, it may be that initially it is not foam destruction throughout the rumen that is required so much as clearance of a vital region, presumably the cardia.

The relief of a bloated cow with anti-foaming agents depends on efficient eructation to expel the freed gas. Any interference with belching could bring about a situation in which the foam, the primary cause of bloating, is broken down, either naturally or with the aid of foam-breakers, but the animal remains bloated. This interference could be caused by a pre-disposing condition of the animal, e.g., a degree of hypocalcaemia (Rydell, 1955), by physiologically active substances in the feed, or by some secondary effect of bloating itself.

No effect of inhibiting agents in the feed in the initial stages of bloat has so far been detected in this work with red clover. The fact that animals protected from bloating by pre-feed treatment with anti-foaming agents eat potent clover to satiety without ill effects would seem to argue strongly against their presence. However, there is the possibility that toxic agents would be absorbed more readily when rumen pressures become elevated during bloat.

Cessation of the rumen movements in severe bloat has frequently been claimed in field cases (Hancock, 1954; Boda *et al.* 1956; Nalson, pers. comm.). Such reports must be treated with reserve, since recording techniques have revealed activity that is not detectable to the eye (Dougherty and Crumb, 1949; Reid, 1957a).

It is possible, however, that pressure within the rumen itself may interfere with belching. Hence, in the acute cases where prompt relief is essential if the animal is to be saved, the trocar or knife appears

to be the safest remedy. If only a small pocket of gas is present, a considerable incision may have to be made to remove solid material that blocks the opening. The usefulness of an anti-foaming agent through the trocar is problematical, for, if the animal is in such a condition as to warrant the employment of this instrument, speed is the essential requirement.

Vegetable-oil drenches have proved satisfactory in the field where animals are not in too distressed a condition, and they are now used extensively in New Zealand. The dose rates used vary between 2 and 4 fl. oz. (approximately 60–120 ml. or 90 g. tallow). In later experiments carried out on areas near the laboratory, oil drenches have been used without failure in cases of bloat on pastures with dominant white, red, or subterranean clover, and on kale. A number of cases of bloat in stalled animals fed nitrogen-fertilized, early spring, short-rotation ryegrass have also been successfully treated with oils, which again have been found to give protection when given before feeding potent ryegrass (Fig. 6).

Although in the investigation reported here, no satisfactory solution was found to the problem of providing protection for a reasonable time at a reasonable cost, later work showed that a practical solution lies in pasture spraying (Reid, 1955, and in preparation).

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BREEDS OF RAMS FOR FAT-LAMB PRODUCTION

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Summary

The characteristics of Suffolk, Border Leicester, Hampshire, Dorset Down, South Suffolk, Border Leicester × Southdown and Southdown sires when crossed over Corriedale ewes for fat-lamb production were compared in 1953 and 1954. Similar comparisons were made in 1955 and 1956 between Suffolk, Dorset Down, and Southdown sires crossed over Corriedale and Border-cross ewes. A particular feature of the trials was a comparison of performance when lambs are drafted very early, in 1954 and 1955 at the mean age of 86 days and 95 days respectively. Emphasis is placed on comparisons with the Southdown and the following conclusions are reached:

(1) The heavy sires, Suffolk and Border Leicester, increase weaning weight by approximately 8 lb. at 110 days of age, but at 86–95 days the gain is only 4 lb. The percentage of lambs drafted fat off the mothers is almost the same as for the Southdown, but grading is definitely inferior so that a lower percentage of prime lambs in both singles and twins is drafted. Carcass weight is however increased by 4 lb. with the later drafting and by 2 lb. with 86–95 day drafting.

(2) The medium weight sires—Hampshire, Dorset Down, South Suffolk and Border Leicester × Southdown—increase weaning weight by 6 lb. at 110 days or 3–4 lb. at 86–95 days. The percentage of prime lambs drafted fat off the mothers is the same as for the Southdown in single lambs even at the early drafting, but in the twin lambs the Southdown is slightly superior at early drafting. Carcass weight is increased by 2 lb. at the later drafting and by 1½ lb. at early drafting.

(3) In carcass conformation the Southdown is outstanding, superior to the medium-weight sires, which in turn are superior to the heavy-weight sires.

(4) Early drafting penalizes the heavy sires relative to the Southdown on the score of grading or percentage of prime lambs drafted, and slightly penalizes the medium-weight sire.

(5) The medium-weight sires represent a compromise between rate of growth and conformation. The Hampshire and Dorset Down have been the best of the medium-weight sires and have given very satisfactory performances.

INTRODUCTION

During the last decade, renewed interest has been shown in the type of sire to be used for crossing over Romney, Corriedale, and half-bred ewes for fat-lamb production, and especially in comparison with the Southdown which is the sire most commonly used. Experimental work conducted by Walker (1949) at the Ruakura Animal Research Station and by Coop and Clark (1952) at Canterbury Agricultural College has in the main determined the relative characteristics of the different crosses and hence of the sires. It was shown that the heavy sires such as the Suffolk and Border Leicester produced lambs which killed out at 4–5 lb. higher carcass weight than the Southdown at the same age, while medium sires such as the Ryeland and South Suffolk increased carcass weight by 2 lb. All sires gave the same percentage

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of prime lambs fat off the mothers. By measurement of growth rate and carcass conformation, Coop and Clark (loc. cit.) demonstrated that the breeds which gave the greatest lamb growth rate (live-weight increase), and hence the greatest carcass weight, had the poorest carcass conformation, whereas the Southdown, which gave the slowest rate of growth, was unquestionably the best as far as carcass conformation was concerned. Walker (loc. cit.) produced supplementary evidence from carcass dissection that carcasses by the heaviest sires had the least fat and most muscle while those by the Southdown had the most fat and least muscle.

The present paper describes the results of further work on this comparison of sires. It was designed to investigate two particular aspects of the problem besides providing information of a general type. Firstly, it was desired to widen the range of sires tested to include those on which little or no work was done in the previous study, namely: the Hampshire and the Dorset Down (two breeds recently imported into New Zealand), the Border Leicester × Southdown (a crossbred ram of considerable popularity locally), and the South Suffolk (a new local breed derived by inbreeding from the Southdown × Suffolk cross). Secondly, it was most important to repeat the experiments under conditions of early drafting of lambs at light weights. In the previous trials, Coop and Clark (1952) killed their lambs at mean ages of 122–132 days in three of the four years and at 100 days in the remaining year, while Walker (1949) killed hers at undisclosed ages but probably not earlier than 120 days. At 120–130 days of age Southdown-cross lambs are about 33–36 lb. in carcass weight. Since 1954 there has been a strong demand, with corresponding premium in price, for very light lambs below 29 lb. in carcass weight. Consequently it became necessary to study relative performance when the lambs were killed at about 90 days, when the Southdown-cross lambs would be 28–30 lb. in weight.

The tests to be described were conducted during the four years 1953–56.

EXPERIMENTAL METHODS

The experiments were conducted on the Ashley Dene property of Lincoln College. This farm is an improved property on thin stony land carrying pastures which are dominantly perennial ryegrass and subterranean clover. The land is subject to early summer drought. The farm carries two ewe equivalents per acre, devoted to fat-lamb production. The techniques used were the same as those of our previous study (Coop and Clark, 1952). As many different rams of each breed were used as was practicable in order to spread any genetic differences in individual rams. The ewes were randomized into sire groups and except during mating all groups were run together and subjected to identical treatment. All ewes were ear-tagged and lambs were tagged at birth and weighed at intervals.

All group mean live weights quoted have been corrected for age to the mean age of all lambs in any particular year, the corrections being on the basis of growth rates of 0.5 lb./day for singles and 0.4 lb./day for twins, these being approximate values obtained over several years. Carcass weights of lambs fat off the mothers have also been corrected for age by 0.2 lb./day. Differences in group mean ages were in almost all cases less than two days, so that corrections have been small. Drafting

is done on the lambs as they are and in the absence of a satisfactory method of correcting drafting percentage for age no corrections have been made. Lambs that lost their ear tags were excluded from analysis. For the sake of convenience of management the very late-lambing ewes (about 5% of all ewes) and the dry ewes were usually withdrawn from the mob towards the end of lambing. Any lambs born to these late-lambing ewes were also excluded. Results, including mean birth date, apply therefore only to those identifiable lambs born before the very late-lambing ewes were withdrawn.

The lamb weaning weights have been subjected to statistical analysis by Student's "t" test. This was done by converting individual weaning weight to growth rate by dividing by age and multiplying by 100. Twins were converted to singles by adding to the twin growth rates the mean single-twin difference obtained from all lambs irrespective of group. This gave weaning weights of lambs individually corrected to 100 days, and these were then analysed. It is helpful to anticipate here that these analyses showed that, with the numbers of lambs used in these trials, weaning-weight differences of approximately 3 lb. are required for significance at the 5% level ($P = 0.05$) and 4 lb. at the 1% level ($P = 0.01$).

Results

1953 Trials

A line of five-year-old Corriedale ewes was randomized into six groups each of 60 ewes and mated to two rams of each of the following breeds: Suffolk (S), Border Leicester (BL), Dorset Down (DD), South Suffolk (SS), Border Leicester × Southdown (BL.SD) and Southdown (SD), on 9th March. A group of 30 ewes was sent to a local Hampshire (H) breeder who mated them to one ram only. These ewes were returned after mating and run with the others.

The ewes were mated on pasture, wintered on lucerne hay and turnips, lambed on to greenfeed and carried on pasture until weaning. The mean lambing date was 20 August. The spring and early summer were favourable, supporting ample pasture growth, so the lambs were drafted on 12 December at a mean age of 114 days. Approximately 60% of all lambs were drafted fat to the freezing works and the remainder, averaging 20–25 per group, were weaned on to grass and subsequently fattened on rape—i.e., rape lambs. All except a total of ten lambs were drafted fat on 8 February 1954.

TABLE 1. Live-weight and Drafting Data for Single Lambs, 1953

Sire	No. Single Lambs Weaned	Live Weight 97 days (lb.)	Weaning Weight 114 days (lb.)	% Drafted	Carcass Weight (lb.)	% Primes Drafted	Carcass Weight Primes Only
S	30	64.5	71.5	84	35.6	42	37.0
BL	26	62.6	72.4	87	35.9	57	37.2
H	16	66.5	71.4	88	34.6	67	35.4
DD	25	64.3	70.0	88	34.3	60	35.6
SS	28	60.1	68.0	68	34.4	58	34.9
BL.SD	31	60.8	69.6	71	34.8	61	35.8
SD	23	56.2	62.0	72	32.0	64	32.2

TABLE 2. DRAFTING DATA FOR TWIN LAMBS AND ALL RAPE LAMBS 1953

	Twin Lambs					Rape Lambs (Single and Twin)	
	No. Lambs Weaned	Live Weight 97 days (lb.)	Weaning Weight 114 days (lb.)	% Drafted	Carcass Wt. (lb.)	Live-weight Gains (lb.)	Carcass Wt. (lb.)
S	22	55.3	64.2	20	31.8	16	35.2
BL	29	50.7	58.2	35	31.0	19	33.6
H	12	53.1	57.7	35	31.8	18	32.3
DD	27	53.0	58.3	35	30.4	16	33.2
SS	28	49.0	55.2	30	28.8	14	32.0
BL.SD	16	52.0	59.2	45	30.6	13	31.0
SD	42	49.1	54.2	50	27.8	9	29.2

Note: (i) Each group of the twin lambs drafted contained approximately 50% of second-grade lambs.

(ii) In the rape lambs drafted the percentage of second-grade lambs per group varied from 20–35%. The live-weight gain of the rape lambs represents the gain from weaning (12 December 1953) to drafting (8 February 1954).

(iii) In weaning weight the Suffolk, Border Leicester, Hampshire, and Dorset Down were significantly ($P = 0.05$) better than the South Suffolk and Border Leicester × Southdown which in turn were significantly better than the Southdown. Differences between the first group of four sires and the Southdown were highly significant ($P < 0.01$).

The conclusions drawn from this trial are as follows:

(i) The Suffolk and Border Leicester have increased weaning weight as compared with the Southdown by 10 lb. for singles and 4–8 lb. for twins, whereas the remaining sires have increased it by 6–9 lb. for singles and 1–5 lb. for twins.

(ii) In the single lambs, some sires (Suffolk, Border Leicester, Hampshire, and Dorset Down) gave larger drafts than the remaining sires but, when grading is taken into account and prime lambs only are considered, all sires, except the Suffolk which was inferior, gave the same percentage fat off the mothers. In the twin lambs, the Southdown was superior to all other sires.

(iii) The Suffolk and Border Leicester increased carcass weight of single lambs by 4 lb. for all lambs drafted and by 5 lb. for prime lambs only. The remaining sires increased it by 2½ lb. and by 3 lb. for primes only. The increases in the twin lambs were 3–4 lb. for the Suffolk, Border Leicester, and Hampshire, and 1–3 lb. for the remainder.

(iv) In the rape lambs, all sires gave better live-weight gains than the Southdown, and carcass weights 2–6 lb. higher.

1954 Trial

The 1954 trial was essentially a repetition of that in 1953 in that the same breeds were employed but in every case completely new pairs of rams were used.

The 430 mixed-age Corriedale ewes (excluding two-tooths) were randomized first by age and then by live weight into one group of 100 ewes for the Southdown, another of 30 ewes for the Hampshire and five groups each of 60 ewes for the remaining breeds. Mating began on 10 March.

The ewes were run on pasture all autumn, supplemented in winter with lucerne hay, on greenfeed for 2–3 weeks following lambing, and then back on pasture until drafting. The mean lambing date was 21 August. The late spring and early summer were exceptionally dry; pastures began to dry out in the middle of October and all pasture of lamb-fattening quality disappeared during November. Nevertheless the lambs grew exceptionally well, as they usually do under dry conditions. These circumstances necessitated drafting and weaning at a very early date, on 15 November, when the mean age of the lambs was 86 days. This provided a severe test of early maturity, which was one of the main objectives of this study. All lambs that could be killed for export, irrespective of grading, were taken on 15 November, and these amounted to 70% of all lambs. The undrafted lambs were weaned and, owing to inability of the farm to fatten them, the majority were sold. No records were therefore kept of post-weaning performance.

The results are summarized in Table 3.

TABLE 3. DRAFTING DATA FOR 1954

	Singles						Twins		
Sire	No. Lambs	Weaning Wt. 86 days (lb.)	% Drafted	Carcass Wt. (lb.)	% Prime Drafted	Carcass Wt. Primes Only (lb.)	Weaning Wt. 86 days (lb.)	% Drafted	Carcass Wt. (lb.)
S	38	65.5	76	32.8	42	35.6	54.5	25	27.0
BL	45	62.8	72	31.3	40	33.7	51.0	26	27.8
H	18	62.8	90	30.0	55	32.0	48.3	33	27.7
DD	37	63.3	92	31.1	62	33.1	50.0	30	26.0
SS	46	60.0	80	29.9	50	31.5	48.5	30	26.3
BL.SD	34	59.0	76	30.2	55	32.6	49.6	35	26.2
SD	68	58.0	78	28.8	65	29.6	47.8	40	25.0

Note: (i) There were 38 twin lambs in the Southdown group, 20–30 in the Border Leicester, South Suffolk, and Border Leicester × Southdown, but only 10–15 in each of the remaining ones.

(ii) Most of the twin lambs were second grade. The Southdown, Border Leicester × Southdown and South Suffolk graded best and contained up to 25% of primes.

(iii) Statistical analysis of weaning weight showed the Suffolk to be significantly better than all other sires ($P < 0.05$) and much superior to the Southdown ($P < 0.01$). The Border Leicester, Hampshire, and Dorset Down were significantly better than the South Suffolk, Border Leicester × Southdown, and Southdown. No other differences were significant.

The following conclusions are drawn from the above results:

(i) The live-weight advantages over the Southdown at 86 day weaning are less than with 100–130 day weaning, being of the

order of 5–7 lb. for single lambs by the heavy sires instead of the usual 10 lb., and correspondingly less for the medium sires. In the twin lambs the live-weight gains are reduced to 3–6 lb. for heavy sires and 1–2 lb. for medium sires.

(ii) The percentage of single lambs drafted fat off the mothers is of the same order for all sires, but the Hampshire and Dorset Down appear to be slightly better than all others in this respect. When grading is taken into account and the percentage of prime lambs drafted is considered, the two heavy sires—Suffolk and and Border Leicester—are definitely inferior to the Southdown while the remaining sires, with the exception of the Dorset Down, are slightly inferior. In the twin lambs the position is similar to that in 1953, namely, that the Southdown grades better than the other sires and gives a slightly higher percentage fat off the mothers.

(iii) The carcass weight increases of single lambs by the Suffolk and Border Leicester are of the order of 3 lb. for all lambs and 5 lb. for primes while the corresponding increases for the remaining sires are 1–2 lb. and 2–3 lb. The increases in the twin lambs are of the order 1–3 lb.

The differences between sires in respect to drafting percentage, carcass weight and conformation of single lambs are illustrated in Fig. 1, the figures being the means of the two years 1953 and 1954.

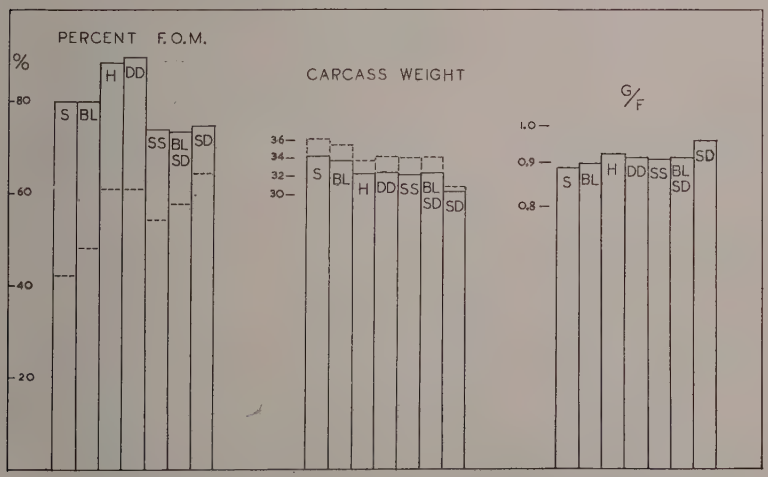

Fig. 1.—Percentage of lambs fat off mothers (FOM), carcass weight, and G/F ratio of single lambs, based on all lambs drafted (full line) and prime lambs only (dotted line).

1955 Trial

In 1955 the trial took a different form. There was on the Ashley Dene farm a mob of nearly 400 ewes, known as the Border Cross mob, in which lifetime individual ewe production records were being obtained. This mob consisted of 150 first-cross Border Leicester × Corriedale ewes, 90 first-cross Border Leicester × Merino ewes and 140 pure

Corriedale ewes comprising all ages from two-tooths to 4-year ewes. They were being used to compare the productivity of the three different types of ewe, described by Coop (1957). To reduce the total amount of recording to be done on the farm there was no valid reason why the different breeds of sire should not be randomized across the breeds of ewe to combine two trials into one. Accordingly each age group of each ewe breed was separately randomized into three, for three sire groups.

It was also decided to reduce the sire groups to three—the Suffolk, Dorset Down, and Southdown, and thereby increase the number of ewes per sire. The Southdown was to act as control, the Suffolk to represent the heavy sires (Suffolk and Border Leicester), and the Dorset Down to represent the medium sires such as the Hampshire, South Suffolk, and Border Leicester × Southdown, because this sire had given very good results in 1953 and 1954. The three groups each of 127 ewes were mated to three entirely new two-tooth Suffolk rams from a stud not previously sampled, three Dorset Downs of which two were two-tooths from a stud also not previously sampled and four Southdowns of which two were new.

The ewes were mated on 9 March. Management was the same as in previous years. The lambing was early, the mean lambing date being 12 August and the weather good so that few lambs were lost. A very high proportion of twins was born and weaned.

TABLE 4. LIVE-WEIGHT AND DRAFTING DATA 1955
First Draft

	Sire	No. Lambs	Live Weight 95 days (lb.)	% Drafted	Carcass Wt. (lb.)	% Primes Drafted	Carcass Wt. Primes (lb.)	% Second Draft	% Store
Singles	S	53	72.2	87	34.9	47	36.8	8	5
	DD	52	73.7	96	34.3	75	35.4	2	2
	SD	42	69.5	88	33.2	70	33.3	5	6
Twins	S	84	61.8	73	29.0	12	35.6	10	15
	DD	90	64.8	77	29.8	30	33.1	17	6
	SD	102	59.5	66	27.8	39	29.5	16	18

Note: (i) The analysis was taken out first for the three ewe breeds separately and then the means of the three ewe breeds averaged to give the above figures. The effect of this is merely to weight the results from the three ewe breeds equally, although the numbers in these were not quite the same.

(ii) The differences due to sires were of the same order of magnitude in all three ewe breeds.

(iii) Percentages "second draft" and "store" are based on the number of lambs present at the first draft.

(iv) Statistical analysis of weaning weight showed that the Dorset Down was significantly better than the Suffolk ($P = 0.02$), which in turn was significantly better than the Southdown ($P = 0.03$), while the difference between the Dorset Down and Southdown was highly significant ($P < 0.01$).

As in 1954, the summer drought set in very early so it was again convenient both in terms of farm management and the objectives of

the study to draft and wean early. This was done on 15 November when the mean age of the lambs was 95 days. Everything that would kill for export was drafted irrespective of grading; 81% of all the lambs were thus drafted fat. The undrafted lambs were not weaned until 11 December when a further 10% of lambs were drafted fat, leaving 9% to be weaned as store lambs. The analysis of carcass grade and weight has been restricted to the first draft at 95 days.

The deductions made from these results are as follows:

(i) Compared with the Southdown, the live-weight increases for the Suffolk were only 2–3 lb., considerably less than expected from previous performance, whereas for the Dorset Down they were of the order 4–5 lb. for both singles and twins.

(ii) The percentage of Suffolk lambs drafted fat off the mothers was approximately the same as the Southdown but the Dorset Down was superior to both. When grading is taken into account, however, and prime lambs only are considered, it is clear that the Suffolk is definitely inferior, while the Dorset Down and Southdown become equal.

(iii) In carcass weight the Suffolk gave an increase of $1\frac{1}{2}$ lb. in both singles and twins and 4–5 lb. for primes only, while the Dorset Down gives 1–3 lb. for singles and twins and 2–4 lb. for primes only.

(iv) Approximately equal percentages of single plus twin lambs for each of the three sires were drafted at the second draft. Consideration of the store lambs left places the Dorset Down superior with only 4%, and the Suffolk and Southdown equal with 10% and 12% respectively.

In the overall picture the Dorset Down has proved superior to the Southdown, while the Suffolk has been inferior on the score of poor grading at light weights.

1956 Trial

The 1955 trial was repeated in 1956, when 420 mixed-age ewes of Border Leicester × Corriedale, Border Leicester × Merino and pure Corriedale were randomized, first by breed and then by age, into quarters, and mated as follows:

105 trial ewes mated along with some other ewes to four Suffolk rams, being the same rams as used in previous years.

210 trial ewes mated along with some other ewes to seven Dorset Down rams of which five had been used before and two were from a third stud not previously sampled.

105 ewes mated to two Southdown rams from a stud not previously sampled.

The rams were put out on 7 March. Management was the same as in previous years. Favourable lambing weather and close shepherding again resulted in very low ewe and lamb losses. As in 1955, a high percentage of twins were reared especially by the Border-cross ewes. Lambing began on 1 August and half the lambs had been born by 13 August which becomes the mean lambing date. The spring and

early summer were wet; there was abundant growth of grass right through to the end of November so it was decided not to kill very early at light weights.

A first draft of lambs was, however, taken on 22 November at a mean age of 101 days, which would be considered early by most standards. The drafter was requested to take all the prime lambs except those at very light weights (less than 26 lb.) and also all the heavy (more than 36 lb.) second-grade lambs. In all, 56% of lambs were taken. Two weeks later, on 6 December, a final draft, representing 27% of the original lambs, was taken and the remaining 17% of lambs were weaned on to rape. From the latter a draft was taken on 10 January 1957 and is referred to as rape lambs. Those still remaining unfattened have been classified as stores.

TABLE 5. LIVE-WEIGHT AND DRAFTING DATA 1956

		No. Lambs	Live Wt. 101 days (lb.)	First Draft %	Second Draft %	Rape Lambs %	Store %	Primes First Draft	Primes Second Draft
Singles	S	50	77.9	66	22	8	4	46	16
	DD	114	76.1	81	18	0	1	67	10
	SD	65	68.3	71	22	6	1	63	18
Twins	S	77	67.1	36	35	13	16	13	10
	DD	123	67.8	54	32	8	6	32	15
	SD	56	62.6	50	36	10	4	41	29

TABLE 6. CARCASS WEIGHTS 1956

		First Draft		Second Draft All Lambs
		All Lambs	Primes Only	
Singles	S	38.7	40.0	37.3
	DD	37.3	38.4	36.7
	SD	34.6	35.2	32.8
Twins	S	37.8	38.0	33.9
	DD	34.2	35.8	32.8
	SD	31.9	32.6	30.6

Note: (i) All percentages are based on the number of lambs present at the first drafting.

(ii) Differences in weaning weight between the Suffolk and Dorset Down were not significant but those between both these sires and the Southdown were highly significant ($P < 0.01$).

The following conclusions are drawn from these tables:

(i) Compared with the Southdown, the Suffolk has increased weaning weight by about 9 lb. for singles and 5 lb. for twins while the

Dorset Down has done almost the same as the Suffolk.

(ii) In percentage of lambs drafted fat, the Dorset Down has proved to be as good as if not better than the Southdown, whereas the Suffolk has been inferior to both. When grading is taken into account, the Dorset Down and Southdown are equally good for single lambs at both first and second drafts, but the Southdown shows a superiority in the twins at both drafts. The Suffolk remains inferior to the other sires in all aspects of grading.

(iii) The mean carcass-weight increase for singles and twins amounts to 5 lb. for the Suffolk and 2½ lb. for the Dorset Down. In prime lambs only, the corresponding increases are 5 lb. and 3 lb.

The differences between sires in respect to drafting percentage, carcass weight, and conformation of both single and twin lambs in the first draft are shown in histogram form in Fig. 2. The figures are based on the means for the two years 1955 and 1956.

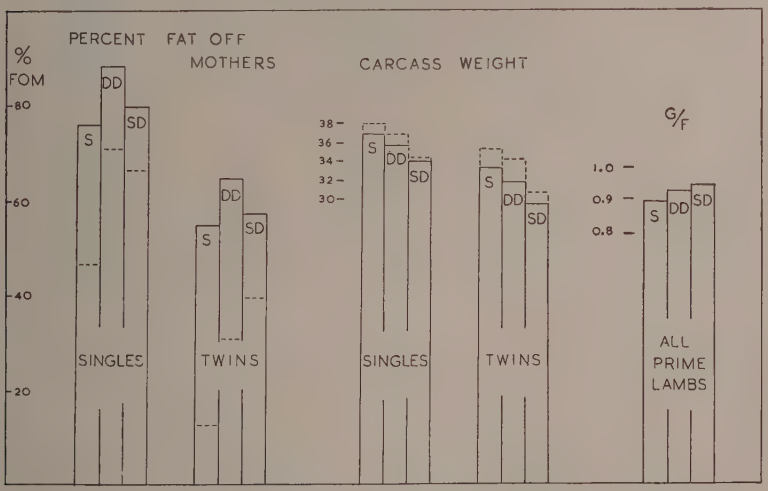

Fig. 2.—Percentage of lambs fat off mothers (FOM), carcass weight, and G/F ratio of single lambs, based on all lambs drafted (full line) and prime lambs only (dotted line).

Barrenness; Ewe and Lamb Losses

Records of ewe and lamb losses until weaning are summarized in Table 7.

TABLE 7. PERCENTAGES OF BARREN EWES, DEAD EWES, AND DEAD LAMBS, 1953–56

Sire	Barren Ewes	Dead Ewes	Dead Lambs
S (+ BL)	3.8	2.3	9.2
DD (+H, SS, BL.SD)	1.8	2.0	11.0
SD	2.5	2.2	8.8

These figures are not easily interpreted apart from showing that any differences are small. In all of these characteristics much of the variation must be attributed to the ewe rather than to the sire. The higher percentage of barren ewes in Suffolk groups has arisen from the performance of two-tooth ewes in 1956. Observation at mating suggests that Suffolk rams are too heavy for small two-tooth ewes and the figures confirm this. In terms of vigour and activity there is no doubt that the Southdown is the least active of all the breeds tested, but when mating is carried out in small paddocks and at rates not exceeding 50 ewes per ram, as was done in these trials, vigour does not appear to be very important. The higher lamb death-rate of the Dorset Down group deserves comment. Hampshires, and to a lesser extent Dorset Downs, are said to leave lambs with large and wide heads and shoulders, causing difficult birth, and this point has been watched carefully. The conclusions reached are that these two sires do leave lambs that are big at birth, which is one reason why they grow faster than the Southdown. In a season when all lambs born are large, the big single lambs from the Hampshire and Dorset Down do give rather more trouble and this must account for part of the mortality. Taking into consideration barren ewes, ewes dying, and lambs born dead or dying before weaning, the overall differences are small and not significant.

Carcass Conformation

Carcass length L, leg length F, and gigot width G (all in mm.), as defined by Palsson (1939), were measured on all prime carcasses,

TABLE 8. CARCASS MEASUREMENTS OF PRIME LAMBS, 1953 AND 1954

	1953					1954				
Sire	Carcass Wt. (lb.)	L mm.	F mm.	G mm.	G/F	Carcass Wt. (lb.)	L mm.	F mm.	G mm.	G/F
S	37.7	596	261	225	0.87	35.4	574	255	226	0.89
BL	36.8	587	253	226	0.89	33.7	563	254	228	0.90
H	36.0	580	238	228	0.93	32.7	556	239	218	0.91
DD	35.0	573	248	226	0.91	33.1	554	245	220	0.91
SS	34.6	566	247	224	0.91	31.5	553	243	218	0.90
BL.SD	35.2	581	244	223	0.91	32.4	551	239	217	0.91
SD	31.0	551	222	214	0.96	29.5	546	222	214	0.96

TABLE 9. CARCASS MEASUREMENTS OF PRIME LAMBS, 1955 AND 1956

	1955					1956				
Sire	Carcass Wt. (lb.)	L mm.	F mm.	G mm.	G/F	Carcass Wt. (lb.)	L mm.	F mm.	G mm.	G/F
S	36.3	575	253	227	0.90	39.5	588	254	228	0.90
DD	34.1	563	240	223	0.93	37.5	571	243	226	0.93
SD	31.3	539	232	219	0.94	34.2	550	228	219	0.96

irrespective of whether they were single or twin. It was felt that a comparison based on lambs falling within a particular grade was better than one based on all lambs in which there would be variable proportions of second-grade lambs in the different groups. The mean measurements for 1953 and 1954 in which all ewes were Corriedale are given in Table 8, and for 1955 and 1956 when the ewes included Border Leicester crosses, are given in Table 9.

Of these measurements the G/F ratio is the best single index of conformation since, amongst other things, it is relatively independent of weight. A high value indicates a well filled blocky hindquarter. These tables show that the Southdown is undoubtedly superior to all other sires, having a G/F ratio that has varied from 0.94–0.96. At the other extreme is the Suffolk (and Border Leicester) which, at carcass weights 5 lb. heavier than the Southdown, has G/F ratios varying from 0.87–0.90. Between these two lie the group of sires with intermediate values of G/F. In 1953 and 1954 when all four—Hampshire, Dorset Down, South Suffolk, and Border Leicester × Southdown—were used, the mean G/F ratio was 0.91 and within the group all were very similar except the Hampshire in 1953. Again in 1955 and 1956 when only the Suffolk, Dorset Down, and Southdown were used, the Dorset Down occupied an intermediate position with G/F ratios of 0.93 and 0.94, tending to be much nearer the Southdown than had been the case in the two previous years. This could mean either that the Dorset Down is in fact better than the 1953 and 1954 results indicate, and is therefore better than the average of the medium sires, or that all four of the medium sires of which the Dorset Down may be representative are better than the 1953 and 1954 results would indicate. Distribution curves of G/F ratios for the different sires show that the carcasses by the South Suffolk and Border Leicester × Southdown are slightly more variable in conformation than those by the old-established breeds such as the Southdown and Suffolk.

In 1956, six prime lambs of representative weight by the three sires and all out of pure Corriedale ewes were taken for dissection. The hind leg and loin of each lamb were dissected into muscle, fat, and bone, while the cross-sectional length (a) and depth (b) of the longissimus dorsi muscle and the depth of fat (c) covering it were measured as described by Palsson (1939). The mean figures are given in Table 10.

TABLE 10. COMPOSITION OF LEG AND LOIN IN TERMS OF MUSCLE, FAT, AND BONE

Sire	Carcass Wt. (lb.)	Leg			Loin			Longissimus Dorsi (mm.)		
		Muscle (%)	Fat (%)	Bone (%)	Muscle (%)	Fat (%)	Bone (%)	a	b	c
S	36.3	67.5	18.5	14.0	47.1	43.6	9.3	50.3	26.3	4.4
DD	34.7	69.4	17.2	13.4	49.5	41.5	9.0	51.0	26.3	4.5
SD	32.2	67.5	18.7	13.8	46.5	44.5	9.0	49.0	28.7	4.6

There was considerable variation in the composition of individual carcasses within each group, so that small differences are of doubtful

significance. However, broadly they show that any differences are small in respect of percentage of muscle and fat in lambs of the same age and in which the Suffolk and Dorset Down exceed the Southdown in carcass weight by 4 and 2 lb. respectively. If any difference is real, it indicates that the Dorset Down produces a meatier type of carcass as both leg and loin contained 2–3% more muscle than the Southdown. On the other hand the differences in shape of the longissimus dorsi muscle were fairly consistent. They show that the Southdown has a deeper and more round cross-section of muscle, which is the more desirable type.

Financial Returns

The financial returns per lamb have been calculated from actual performance and financial receipts after making the following assumptions:

(i) that the total number of twin lambs present at first drafting is the same as the total number of singles; that is, the mean of single and twin performance is taken;

(ii) that unfattened lambs have a value of 40/- per head. The price schedule and the mean returns to the nearest sixpence are given in Table 11.

TABLE 11. PRICE SCHEDULE AND FINANCIAL RETURNS PER LAMB, 1953-1956
(Price in pence per lb.)

Grade	Wt. (lb.)	1953	1954	1955	1956
Prime	20–28	20	24	25	24
	29–36	20	24	24	22
	37–42	19⅝	22	21	20
	43–50	19¼	20	19	18
Second Grade	20–28	18⅞	23	24	23
	29–36	18⅝	23	23	21
	37–42	18⅞	20	21	19
Sire		Value per Lamb			
S(+BL)		55/–	49/–	60/–	60/–
DD (+H, SS, BL.SD)		53/6	48/6	62/–	60/6
SD		50/–	46/–	58/–	58/–

The drafting data already presented show that the heavy sires such as the Suffolk produce lambs about 4 lb. (or 12%) heavier in carcass weight than the Southdown, while the intermediate sires such as the Dorset Down increase it by 2–3 lb. (7–8%). Under the post-war schedule typified by 1953, there was little price differential or penalty for the heavier lamb, so that the extra weight is reflected in a corresponding increase in value. Since 1953, the price schedule has altered drastically by providing a premium for very light lambs and

penalizing the heavy ones. Under this system, in 1954–56 the extra weight provided by the Suffolk has returned only 2/- to 3/- per carcass, or less than 5%. The Dorset Down has in this respect suffered to only a small degree, the gain in value being 6%. In other words, the medium sires give a more consistent advantage under the two types of price schedule. It should also be noted that the returns from the heavier sires have been greater than from the Southdown, even in the years (1954, 1955) of very early drafting at light weight. This has arisen because the penalty for second-grade lambs has been small in recent years with the result that, for example, a 32-lb. second-grade lamb returns more than a 30-lb. prime.

DISCUSSION

On the basis of previous work, Coop and Clark (1952) showed that the sires then tested could be classified into three main groups, as follows:

(1) The heavy sires, such as the Suffolk, Dorset Horn, and Border Leicester, which increased weaning weight by 10 lb. and carcass weight by 4 lb.

(2) The intermediate or medium sires, such as the Ryeland and South Suffolk, which increased weaning weight by 4–8 lb. and carcass weight by 2 lb.

(3) The light-weight sire—the Southdown—against which all other sires are measured.

The lambs were taken to fairly heavy weights, fashionable at the time, the Southdown lambs being of the order of 34–36 lb. No differences in percentage of lambs fat off mothers or of grading were observed, though it was shown that in carcass conformation the Southdown was easily the best and the heavy sires the poorest.

The results of this later series of trials have shown that the above conclusions are substantially correct, though they require some modification if they are to be applicable to very young lambs killed at light weights, for example when the Southdowns are at 28–30 lb. carcass weight.

The various features of the comparison of sires in this new series will now be discussed, on the basis that the Hampshire, Dorset Down, South Suffolk, and Border Leicester × Southdown all fall within the intermediate or medium group of sires.

Rate of Growth

As in the previous series, the heavy sires Suffolk and Border Leicester have been shown to confer on their progeny a high rate of growth as measured by weaning weight or live-weight gain. In terms of weaning weight, the increase over the Southdown has been 8 lb., (rather more for singles and less for twins) when the lambs are taken to about 110 days of age, but when they are weaned at 86–95 days the increase is only 4 lb. The medium sires—Hampshire, Dorset Down, South Suffolk and Border Leicester × Southdown—have given increases in weaning weight of the order of 5–6 lb. at 110 days and 3–4 lb. at 86–95 days. Of the four sires, the Hampshire and Dorset Down have given rather greater growth rates than the remaining two.

Drafting Percentage

The percentages of lambs drafted fat off the mothers is given in Tables 1–6. These show that in single lambs the Suffolk and Border Leicester rams give as high a percentage (about 80% mean) as the Southdown, even during the years of very early drafting. However, the Suffolk and Border Leicester lambs have not graded as well as the Southdowns, so that, when the percentage is expressed in terms of prime lambs only, the two heavy sires are definitely inferior, the mean percentage being 45% as compared with 66% for the Southdown, and this difference has been approximately the same in all four years. In the twin lambs, the Suffolk and Border Leicester have been inferior to the Southdown both in total lambs drafted irrespective of grading, 40% as compared with 50%, and in prime lambs only drafted, 11% compared with 26%.

Within the medium group of sires, the South Suffolk and Border Leicester × Southdown in the two years when they were tested gave percentages of total lambs drafted and primes only drafted which were the same as for the Southdown in single lambs, but in the twin lambs both total drafted and primes only drafted were slightly lower than the Southdown, e.g., total drafted 30–40% compared with 50%. On the other hand, the Hampshire (1953, 1954) and Dorset Down (1953–56) have given a higher percentage of single lambs drafted, 89% compared with the Southdown 77%, but when prime lambs only are considered the percentages are identical at 66%. In the twin lambs, the total drafted has been the same, 50%, and in prime lambs only, the Hampshire and Dorset Down have been only very slightly inferior, 21% compared with 26%.

It is clear that the contention of Coop and Clark (1952) and Walker (1949), that all sires give the same percentage of lambs fat off the mothers without sacrifice of prime grading, ceases to hold good under early drafting, especially in twin lambs. Drafting percentage, grading, and carcass weight are all inter-related. It is significant that in all of these trials fewer second-grade lambs have been taken from the Southdown group. This is because the drafter hesitates to take very light 24–26 lb. second-grade Southdown lambs whereas he will draft lambs of equal conformation and fatness by the heavier sires because such lambs have more weight. It must also be appreciated that a first draft containing a high proportion of second-grade lambs penalizes carcass weight and grading in subsequent drafts from that group, since these heavier second-grade lambs would have a better chance of becoming prime.

Carcass Weight

The mean increase in carcass weight due to the Suffolk and Border Leicester rams was 3.3 lb. in both single and twin lambs drafted, increasing to 4–5 lb. when prime carcasses only are considered. These differences were smaller in the years of very early drafting and larger in those of later drafting. For example, the gain in both single and twin lambs drafted was only 2 lb. in 1954 and 1955 but increased to over 4 lb. in 1953 and 1956. Differences of the order of 4 lb. also existed in second drafts and rape lambs.

The four medium sires gave increases which amongst themselves were of the same order of magnitude, the means of the four years being:

single lambs 2 lb., prime single lambs 2.8 lb., twin lambs 2.0 lb., prime twin lambs 3.3 lb. Again the 2-lb. differences for single and twin lambs were down to 1½ lb. in the years of very early drafting and up to 2½ lb. in 1954 and 1956.

Thus the carcass-weight increases in the two years of 101–114 day weaning have been of the same magnitude as those previously reported (Coop and Clark 1952), namely, 4 lb. for the heavy sires and 2 lb. for the medium ones. But with 86–95 day weaning these differences are reduced to 2 and 1½ lb. respectively so that under conditions of such early weaning the carcass-weight gains are considerably reduced.

Carcass Conformation

The data presented in Tables 8 and 9 show that the Southdown has no real rival for the production of the very blocky carcass. The ratio of gigot width to leg length (G/F) of the Southdown lambs has been consistently of the order of 0.96. At the other extreme the ratio for the Suffolk and Border Leicester has been in the range 0.87–0.90 indicative of the much longer leg. The intermediate sires have occupied a position between these extremes. In the years 1953 and 1954, when four sires of this category were used, the G/F ratios tended to be nearer the Suffolk than the Southdown, but in 1955 and 1956 when the Dorset Down only was used the G/F ratio tended more to the Southdown. Within the intermediate sires there is a suggestion that the Hampshire and Dorset Down have conformation slightly superior to the South Suffolk and Border Leicester × Southdown sires. It must be remembered that the carcasses by the different sires were of the same age and were all prime grade but that there were weight differences of the order of 5 lb. for the heavy sires and 3 lb. for the medium ones. In other words, a Southdown lamb weighing 30 lb. (carcass weight) has a better conformation than a Dorset Down weighing 33 lb. or a Suffolk weighing 35 lb.

The carcass composition data are rather inconclusive. Taking the mean of the leg and loin dissections they suggest that the 36 lb. Suffolk has the same proportion of fat and muscle as the Southdown at 32 lb., while the Dorset Down at 34½ lb. has slightly more muscle and less fat than either of the other two.

The present work has confirmed that the Southdown occupies a unique position in the scale or classification of sires. It stands apart from all others that have been tested in this and previous series as the sire par excellence for the production of light-weight lambs. Relative to other sires it produces lambs with the slowest growth rate as measured by live-weight gain, the lowest carcass weight, but the best conformation. Since it is so widely used in New Zealand, the Southdown has been selected as the control against which other sires are assessed.

The present work with the Suffolk and Border Leicester has shown that these sires occupy one extreme in the range of all sires, and that with normal or late drafting the conclusions of Coop and Clark (1952) are approximately correct, but with early drafting (86–95 days) at light weights the live-weight and carcass-weight advantages and grading have fallen off relative to the Southdown. Under these conditions fewer prime lambs are drafted fat off the mothers and carcass-weight gains

are reduced to 2 lb. The conformation of Suffolk and Border Leicester lambs is inferior to those of the Southdown. With lambs of 110–130 days of age, killing at 35–40 lb. carcass weight, the commercial drafting and subsequent grading are not sufficiently discriminating to penalize Suffolk and Border Leicester lambs for grade, but it is now evident that with younger lambs at lighter weights (30–35 lb.) discrimination is exercised and a higher proportion are down-graded to second grade. Within the heavy-sire group there is a tendency for the Suffolk to occupy the extreme position since it has given slightly higher growth rate and carcass weight and a poorer conformation than the Border Leicester.

There seems to be no reason to drop the "medium" or intermediate-group classification suggested from our previous work. In that work only the Ryeland and South Suffolk of this group were tested. The present work shows that the Hampshire, Dorset Down, and Border Leicester × Southdown may be added. All the sires of this group give lambs which, in growth rate, carcass weight, and conformation occupy an intermediate position, roughly half way between the heavy sires and the Southdown. The breeding of the South Suffolk and the Border Leicester × Southdown suggest theoretical reasons why these two at least should occupy a position half way between the parent breeds. The South Suffolk is derived by inbreeding from the Southdown × Suffolk cross and there has been insufficient time for selection to have altered its original inheritance greatly, while the Border Leicester × Southdown is normally used as a first-cross ram. The 1953–56 series of tests has supported the previous observation that sires of this group increase weaning weight by about 6 lb. and carcass weight by 2 lb., and give the same percentage fat off the mothers either as total lambs drafted or as primes only. However, when drafting is done at 86–95 days the weaning-weight advantage drops to 3–4 lb., and carcass-weight to 1½ lb. The relative drafting and grading of single lambs is not altered, but the twin lambs by sires of this group have not graded quite as well as the Southdown at these very early ages and light weights. The conformation of lambs by these sires is inferior to those by the Southdown but better than those by the heavy sires.

In 1953 and 1954, when all the different sires were tested, the Hampshire and Dorset Down within this group gave growth rates, drafting percentages, carcass weights, and carcass conformation that were slightly better than the other sires of the group. In 1955 and 1956, it was not possible to test six or seven sires as in previous years and the Dorset Down was chosen to represent the intermediate group, the results of 1953 and 1954 having showed it to be a very good sire. At this stage the tests do not differentiate between the Hampshire and Dorset Down and both are still regarded as being of approximately the same value. The combined results of the Hampshire over two years and the Dorset Down over four years show that their lambs give weaning weights that have tended to be higher than those of the South Suffolk and Border Leicester × Southdown and towards those of the Suffolk. Significantly more single lambs by the Hampshire and Dorset Down than by the Southdown have been drafted fat off the mothers, and it is only in twin lambs killed at a very early age that the drafting of the Southdown has been superior, and then only by a small margin. Coupled with this is the observation that the Hampshire in 1953 and the Dorset Down in 1955 and 1956 produced lambs with conformation above

average for the intermediate group. In other words, these sires produce lambs which are 2 lb. heavier than the Southdown in carcass weight, give a drafting percentage and grading for all practical purposes as good as the Southdown under both early and late drafting, and have a better conformation than one would expect for the weight increase gained. This is expressed in another form in Table 11, which gives the financial returns per lamb. The heavy sires (Suffolk) give a 10% margin of superiority under late drafting with a price schedule favourable to weight, but this drops (1954–56) significantly to 5% under early drafting and the premium for light-weight lamb. On the other hand, medium sires have given a consistent superiority of 5–7% under all conditions.

The group of medium sires clearly represents a compromise between weight and conformation. It is our belief that a slight distinction can be made within the group to the effect that the Hampshire and Dorset Down occupy the most favoured position within this compromise. Undue mention has perhaps been made of the Dorset Down since it was used more extensively in the trials to represent the medium sires, but the other medium sires also gave good results and praise for one member of this group must not be at the expense of the remaining ones.

Throughout this and our previous work an endeavour has been made to determine the relative merits of the various sires used for fat-lamb production. The results obtained show that carcass conformation and grading are inversely related to growth rate and carcass weight. On the basis of any of these four characteristics it is possible to place the sires in order of merit, for example in growth rate, starting with the Suffolk and ending with the Southdown. However some of the inter-sire differences are very small and the tests have not been on a sufficiently large scale to differentiate between some sires. In the circumstances therefore an alternative classification has been adopted in which three broad groupings are made—the heavy, medium, and light sires. There has been no difficulty in placing the Suffolk, Border Leicester, and Dorset Horn in the heavy group, and the Southdown as the sole occupant of the light group. All the remaining sires tested have been placed in the medium group, although there are reservations as to whether or not the Hampshire and Dorset Down should not be placed on their own in a fourth group. This classification recognizes both major differences between groups and minor differences between members of each group.

This journal is not the place to discuss the practical and commercial implications arising from the results described. This would in any case be very difficult, because it is clear that no one sire possesses all the virtues and that each represents a compromise between rate of growth and carcass weight on the one hand and conformation, grading, and percentage fat off the mothers on the other hand. Further, quality is not a fixed entity. In the pre-war days there was a premium for the under-36-lb. lamb. After the war this premium was much reduced and lambs of all weight were in demand. Since 1954 and 1955 the light-weight premium has been re-introduced and an extra premium paid for the extra-light lamb, but it is by no means certain that the present demand for the very light lamb is not a revolt against the too-fat lamb rather than the too-heavy lamb, if for no other reason than that the

penalty for second-grade lambs is now much reduced. In other words, quality is neither defined nor fixed. Under such conditions it is considered better merely to give the results of these trials, which can then be interpreted at any time to meet any particular set of farming practices or market conditions.

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PHOTOSENSITIVITY DISEASES IN NEW ZEALAND

XI. COLLECTION AND PRESERVATION OF PASTURE THAT PRODUCES FACIAL ECZEMA

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Summary

1. It has been demonstrated that liver damage characteristic of facial eczema can be produced in penned lambs and guinea pigs by feeding to them green pasture that produced liver damage in grazing lambs when it was growing.
2. The toxicity of this pasture can be preserved to some extent by drying in air having a temperature between 95 and 110°C. when it enters the pasture.
3. A method has been devised for determining toxic periods by systematic liver examination of lambs introduced into experimental paddocks at short intervals.
4. The method of collecting, drying, and storing toxic pasture for chemical determination of the liver-damaging substance is described.

Introduction

All efforts to transmit facial eczema from affected to healthy sheep starting with those of Gilruth (1908) have completely failed and there is no reason to believe that facial eczema is an infectious disease. In 1938 it was known that hepatogenous photosensitisation could be produced by the ingestion of plants which contained liver-damaging substances. The literature has been reviewed by Clare (1951). Careful examination of paddocks in which facial eczema had developed failed to discover any weed or fungus which could be incriminated. The hypothesis was therefore propounded that the liver damage was caused by some substance which developed in one or more pasture species under the peculiar climatic conditions which are associated with the occurrence of facial eczema. To test this hypothesis it was decided to cut pasture from a paddock in which facial eczema occurred and feed it to lambs in pens. It had been observed that if lambs were introduced into a paddock immediately symptoms of facial eczema appeared in sheep grazing in it, the introduced lambs usually remained healthy. It therefore appeared that if a liver-damaging substance did develop in pasture plants, it was present in dangerous concentration for only a limited period and it was thus necessary to collect and feed pasture prior to the development of symptoms in grazing sheep. As warm autumn rains appeared to precede all outbreaks of facial eczema, it was decided to commence collecting and feeding following the advent of such rains.

Experimental

The first trials were made in 1939 and 1940 with pasture collected from a farm at Karamu, about 10 miles south-west of Hamilton.

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Although some clinical cases of facial eczema had developed on this farm in many preceding years, no clinical cases and very little liver damage developed in grazing sheep during 1939 and 1940. The negative results obtained in pen feeding trials were therefore inconclusive.

In 1941 the work was transferred to a farm at Whakaki, about 5 miles west of Wairoa. A paddock of 10 acres on a very fertile, alluvial flat carrying a pasture dominant in perennial reygrass and white clover was divided into three fields. Lambs from surrounding hill country, on which facial eczema did not occur, were introduced at intervals and rotated through these fields, spending three days in each. Van den Bergh tests were conducted on blood collected from all lambs at weekly intervals. The results are shown in Table 1.

TABLE 1. RESULTS OF VAN DEN BERGH TESTS

Date Introduced	No.	Positive to van den Bergh	Skin Lesions	First Positive van den Bergh	Last Positive van den Bergh
6.1.41	60	15	7	11.3.41	25.3.41
4.2.41	10	—	—		
18.2.41	10	2	1	20.3.41	25.3.41
4.3.41	10	4	2	11.3.41*	25.3.41
12.3.41	10	5	3	25.3.41	1.4.41
18.3.41	10	—	—		
26.3.41	10				
2.4.41	10				
9.4.41	10			1 on 8.5.41 lasted one day only	
17.4.41	10				

* One lamb became photosensitive on 10.3.41

TABLE 2. FRESH HERBAGE FED TO PENNED LAMBS

Period	Average Daily Consumption (lb.)	Liver Damage
9.1–29.4.41	6.8	Moderate
9.1– 5.2.41	3.9	Very slight
6.2– 2.3.41	4.2	None
5.3– 2.4.41	3.9	Definite
26.3–30.4.41	4.2	None
26.3–30.4.41	8.3	Serious

From 9 January, grass was mowed daily and fed green to penned lambs. These lambs were taken from the same flock as those used in the grazing trials. The results are shown in Table 2.

With the exception of the last lamb the grass fed was cut from the section in which the lambs were grazing. It was noticed that on the second and third days samples were heavily contaminated with faeces. For the last lamb, pasture was cut from the section into which lambs were introduced for one day and for the next two days from the section into which they would go next. This greatly reduced faecal contamination and doubled the intake by the penned lamb.

This trial showed conclusively that liver damage could be produced by feeding cut green grass and thus greatly strengthened the hypothesis that a liver-damaging substance develops in one or more pasture plants.

It was obviously desirable to determine the chemical identity of the liver-damaging substance. Before this could be attempted, however, it was necessary to discover some means of preserving the pasture which would not destroy the liver-damaging substance. During 1939 and 1940, freezing had been tried at Karamu. As cut grass did not prove toxic in those years, the efficacy of this method was not determined. However, as the chemistry was to be undertaken at Wallaceville and Ruakura, this method did not appear feasible for grass collected at Whakaki as transport in the frozen state would have presented considerable difficulty. It was therefore decided to try boiling and sealing in tins and drying by hot air.

Very little liver damage occurred in grazing lambs at Whakaki during 1942 so no progress was made. In 1943, severe liver damage occurred in the experimental lambs at Whakaki, which were rotated through the same three fields as those used in 1941, again spending three days in each. Pasture was mowed from these fields on the first two days on which lambs were grazing in a field, and on the third day from the field into which they were going next. A total of 1,600 lb. of dried grass was collected, and grass was also preserved in 378 tins holding approximately 6 lb. green pasture each. In addition, approximately 790 lb. of dried grass was collected from paddocks in Gisborne and Wairoa areas in which liver damage occurred. This preserved grass was sent to Wallaceville where it was fed to penned lambs which had been born on the station where facial eczema had never occurred. Some preserved grass was also fed to guinea pigs. The results are shown in Table 3.

It was thus demonstrated that pasture could be dried without destroying the liver-damaging substance, but boiling and canning appeared to have reduced toxicity. Since 1943, drying has been adopted as the standard technique. Two sizes of dryer have been used, a small one with a capacity of 8–10 lb. DM per hour and a larger one with a capacity of 40–50 lb. DM per hour. The design of the two machines is somewhat different but their essential principle is the same. Hot air is drawn from a coke-fired furnace by electric fan and is forced by way of a tunnel up through a pair of adjacent bins in which mesh trays are set to carry the grass. The tunnel conveying hot air to the bins is centrally divided by a hinged shutter which can be swung over to divert the whole flow of air to either bin as desired.

TABLE 3. PRESERVED HERBAGE FED TO PENNED LAMBS AND GUINEA PIGS

Source of Grass	Date Cut	Preservation	Experimental Animals	Period of Feeding	Initial Weight	Final Weight	Daily Intake	Liver Damage
Whakaki	25.1–17.2 5–8.3 24–29.3	Dried	Sheep 81 Sheep 811 10 guinea pigs	36 days 36 days 45 days	27.0 kg. 27.4 kg. 690 g.	27.1 kg. 34.8 kg. 740 g.	870 g. Av. 90 g.	Mild Mild 9 none 1 doubtful
Whakaki	25.1–4.3	Dried	Sheep 876	36 days	26.4 kg.	29.4 kg.	840 g.	F.E.
Whakaki	18.2–4.3 9–18.3	Dried	Sheep 866 Sheep 843 10 guinea pigs	36 days 36 days 45 days	25.0 kg. 26.4 kg. 590 g.	27.4 kg. 29.3 kg. 670 g.	890 g. Av. 88 g.	Mild Typical 7 none, 1 mild, 2 typical
Whakaki	25.1–21.4	Boiled and Canned	Sheep 921 Sheep 821 6 guinea pigs	40 days 40 days 45 days	23.0 kg. 36.0 kg. 675 g.	27.0 kg. 35.3 kg. 666 g.	3190 g. Av. 330 g.	None Very mild None
Gisborne area	13.2, 13–15.3, 6.4, 9.4	Dried	Sheep 906 Sheep 88 Sheep 823 10 guinea pigs	36 days 36 days 36 days 45 days	22.6 kg. 27.2 kg. 21.6 kg. 640 g.	27.1 kg. 31.4 kg. 27.2 kg. 690 g.	990 g. Av. 790 g. 88 g.	Severe Severe Severe 1 doubtful, 6 mild, 3 severe
Whakaki Regrowth on bare paddock	9.4.43	Dried	Sheep 804 3 guinea pigs	14 days 24 days	31.4 kg. 666 g.	30.1 kg. 715 g.	710 g. 100 g.	Typical 2 doubtful, 1 typical

Thermocouples are set in the hot air stream just prior to its entering the bins and temperature is indicated by a galvanometer calibrated to °c. The temperature is controlled to within a range of 95–110°c. by admixture of cold air with the hot, as it leaves the furnace. For this purpose a manually operated vent is set to permit the entry of the desired amount of cold air.

Freshly mown grass is spread on the drying trays to a depth of 6–8 in. and covered with mesh frames to prevent its escape. The hot air is passed through each bin alternately for a period of 10 minutes. While one bin is in operation, grass in the other is thoroughly mixed to ensure even drying and complete dryness is adjudged when the grass will crumble to a powder if rubbed between the palms.

Under normal conditions fresh grass takes four 10-minute spells to dry, but the presence of free precipated moisture extends the time considerably. Rain-sodden grass can require up to seven 10-minute spells.

There is some evidence that drying reduces the toxicity of pasture. Although quite severe liver damage has been produced by feeding dried pasture, icterus and photosensitisation have never been produced in lambs and seldom in guinea pigs, though on several occasions both had occurred in lambs grazing in the paddocks from which the pasture had been cut. On two occasions dried pasture gave completely negative results when fed to young guinea pigs although severe liver damage had occurred in lambs grazing in the paddock from which the pasture was cut. In general, however, the drying method now used has proved satisfactory for preserving toxic pasture for chemical examination.

Since 1945, the systematic collection and drying of pasture has been conducted on an experimental farm of 68 acres at Manutuke, approximately 9 miles south of Gisborne. Dried pasture capable of producing liver damage in lambs or guinea pigs has been collected from this farm in 1945, 1949, 1950, 1951, 1955, 1956, and 1957. The following procedure is now used at Manutuke: An area of 10 acres divided into five equal paddocks is used. The pasture is predominantly perennial ryegrass and white clover and it has a very bad history of facial eczema. During summer the pasture is kept short, either by overgrazing or with the aid of a motor mower. In January, before any liver damage has occurred in lambs in the district, 300 lambs are bought from a hill farm. From 40 to 60 of these are placed in one of the 2-acre paddocks and rotated through these, spending two days in each. The remaining lambs are grazed on brassica crops, usually turnips and thousand-headed kale, which have never been known to produce liver damage. From about 1 February, 10 lambs are drafted into the experimental paddocks each week. Two of the first large group are removed each week. One is killed immediately and the other is grazed for three weeks on crops and then killed. This latter procedure has been adopted because it has been found that liver damage progresses after feeding on toxic pasture ceases. After three weeks' grazing, each group of 10 lambs is removed from the experimental area. Five are killed immediately and the other five after grazing for 3 weeks on crops. All livers are carefully examined and the degree of liver damage is recorded. At one time livers were examined histologically. Biopsy using the technique of Dick (1944) was also tried. This had the

advantage of permitting successive estimates of the liver damage in the same lamb. It was found, however, that the sample obtained did not always give a correct estimate of the liver damage which may vary in intensity in different parts of the liver. Assessment is now made by macroscopic examination of the whole liver, noting particularly the increase in lobular mottling, the increase in thickness of bile duct walls, and the degree of cirrhosis. While such an examination may miss fine histological changes, it is sufficiently accurate to detect any degree of toxicity in pastures which is of sufficient intensity to make the sample useful for chemical examination.

Although in the 1941 experiments the van den Bergh test gave a good indication of the periods during which pasture was toxic, experience has since shown that quite severe liver damage can develop without any bilirubinaemia. No other liver-function test has proved capable of detecting liver damage which is not accompanied by bilirubinaemia. It has therefore been necessary to adopt the method described.

TABLE 4. LIVER DAMAGE IN INITIAL GROUP

40 Lambs from 14.1.57

Date Removed	Date Killed	No. Killed	Liver Classification—No. of Lambs Showing:		
			Normal Liver	Slight Lesions	Severe Lesions
12.2.57	12.2.57	1	1	—	—
19.2.57	19.2.57	1	1	—	—
19.2.57	12.3.57	1	—	—	1
26.2.57	26.2.57	1	1	—	—
26.2.57	19.3.57	1	—	1	—
5.3.57	5.3.57	2	—	2	—
5.3.57	26.3.57	Missed	—	—	—
12.3.57	12.3.57	1	—	—	1
12.3.57	2.4.57	1	—	—	1
19.3.57	19.3.57	1	—	1	—
19.3.57	9.4.57	1	—	—	1
26.3.57	26.3.57	1	—	—	1
26.3.57	16.4.57	1	—	—	1
2.4.57	2.4.57	1	—	—	1(1)
2.4.57	23.4.57	1	—	—	1
9.4.57	9.4.57	1	—	1	—
9.4.57	1.5.57	1	—	—	1
16.4.57	16.4.57	1	—	—	1
16.4.57	3.5.57	1	—	—	1
23.4.57	23.4.57	1	—	—	1
1.5.57	1.5.57	1	—	1	—
8.5.57	8.5.57	19	—	4	15(3)

Numbers in brackets indicate clinical cases.

The results of liver examination for 1957 are shown in Tables 4 and 5, as an example of the way in which periods of toxicity are determined.

TABLE 5. LIVER DAMAGE IN GROUPS OF LAMBS ADDED FROM 29.1.57

No. in Group	Date Added	Date Removed	Date Killed	No. Killed	Liver Classification—No. of Lambs Showing		
					Normal Livers	Slight Lesions	Severe Lesions
10	29.1.57	19.2.57	19.2.57	5	4	1	—
			12.3.57	5	—	3	2
10	5.2.57	26.2.57	26.2.57	5	2	3	—
			19.3.57	5	—	1	4
10	12.2.57	5.3.57	5.3.57	4	4	—	—
			26.3.57	6	1	5	—
10	19.2.57	12.3.57	12.3.57	5	2	2	1
			2.4.57	5	—	2	3
10	26.2.57	19.3.57	19.3.57	5	1	2	2
			9.4.57	5	—	2	3
10	5.3.57	26.3.57	26.3.57	4	—	1	3(2)
			16.4.57	5	1	2	2
10	12.3.57	2.4.57	2.4.57	5	1	2	2
			23.4.57	5	2	3	—
10	19.3.57	9.4.57	9.4.57	5	1	4	—
			30.4.57	5	2	3	—
10	26.3.57	16.4.57	16.4.57	5	4	1	—
			8.5.57	5	5	—	—
10	2.4.57	23.4.57	23.4.57	5	5	—	—
			8.5.57	5	4	1	—
10	9.4.57	30.4.57	30.4.57	5	5	—	—
			8.5.57	5	5	—	—

Numbers in brackets indicate clinical cases.

Liver lesions were detected in lambs removed from the experimental paddocks on 19 and 26 February. Lambs grazing in the experimental paddocks from 12 February to 5 March had normal livers when killed on the latter date, but those which were killed after grazing on crops for three weeks after 5 March showed slight liver damage. Some of each group of lambs entering the experimental paddocks from 19 February to 19 March showed liver lesions. Lambs entering the experimental paddocks on and after 26 March developed little or no liver damage.

1.32 inches rain fell on 3–6 February after 20 days of hot weather without rain. From 3–7 February temperatures were high—maximum 72.8° to 83.0°, minimum 56.3° to 66.4°, and grass minimum 48.9° to 64.4°F. From 7 February to 6 March there was another warm dry spell during which only 0.66 inches rain fell on three separate

occasions. From 7–31 March 6.70 inches rain fell on 17 days. Temperatures were consistently high from 7–20 March—maximum 70.5° to 80.9°, minimum 56.7° to 65.0°, and grass minimum 52.8° to 62.1°F.

It seems certain that the toxicity was initiated by the early February rains. From about 12 February toxicity decreased. It increased sharply with the advent of rain on 7 March. Two lambs which entered the experimental paddocks on 5 March developed skin lesions on 19 and 20 March. From 21 March, temperatures fell and toxicity declined.

Approximately 1,500 lb. dry pasture collected from the experimental paddocks during the autumn of 1957 has been tested by feeding to guinea pigs and proved to have retained its liver-damaging properties.

Pasture is mowed and dried daily from the commencement of the first autumn rains until the weather turns cold late in April. Each bag of dried pasture is labelled with paddock number and date. As soon as liver damage appears in the grazing lambs, the dried pasture for the period incriminated is tested by feeding to young guinea pigs using the technique described by Perrin (1957). In earlier years lambs were used for feeding tests, and because of the quantity required samples cut during toxic periods were bulked. The guinea pig makes it possible to test individual days' collections and to differentiate between the level of toxicity of these.

Dried grass collected at Whakaki during February and March 1943 was still toxic in November. In 1944, mixed dried grass collected at Whakaki and Gisborne in February and March produced liver damage when fed to lambs at Wallaceville in June and July. By September the toxicity had declined considerably and by November it had disappeared completely. A sample of H1 ryegrass collected and dried at Manutuke in April 1951 was shown to be toxic in the paddock shortly after grazing. When held at Ruakura without special storage, toxicity disappeared in 12 months. Since then dried grass which has been proved toxic is coarsely ground and placed in air-tight tins and kept at a temperature a few degrees below 0°C. Under these conditions there has been little evidence of loss of toxicity over a period of up to 18 months (Mr. E. P. White, pers. comm.).

Because of the irregular occurrence of toxicity at any one place, pasture has been collected and dried from a number of areas in addition to the Manutuke experimental farm. Areas with a bad history for facial eczema have been chosen, and pasture has been collected when weather conditions and the appearance of the pasture made toxicity likely. It has not been possible to assess the toxicity of the growing pasture of these areas by the systematic killing of grazing lambs. The guinea-pig test has, however, enabled the toxicity of the dried pasture to be assessed. A number of samples have been collected in this way, which have been sufficiently toxic to be useful for chemical examination. Of particular interest in this regard is pasture which has been regularly mowed on race-courses, show grounds, and other similar areas. In districts subject to facial eczema, such treatment appears to increase the toxicity of pastures dominant in ryegrass.

Acknowledgements

Histological examination of livers was conducted by Dr. C. S. M. Hopkirk. A number of farmers and the committees controlling several race-courses, show grounds, polo grounds, and golf courses have permitted us to collect pasture from their properties. This assistance is gratefully acknowledged.

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BLOAT IN CATTLE

IV. A COMPARISON OF THE CHEMICAL COMPOSITION AND FOAMING PROPERTIES OF EXTRACTS OF BLOATING AND NON-BLOATING CLOVER

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Summary

A serial-dilution technique has been devised for comparing the foaming properties of extracts of bloating and non-bloating clover.

A crude plant macerate was fractionated into extracts containing:

(A) Soluble protein, "saponin", and chloroplasts.

(B) Soluble protein and "saponin".

(C) "Saponin".

When tested under optimum conditions of pH and salt concentration, none of these factors showed any relationship in foaming properties with the bloat-promoting potential of the fresh clover.

The only satisfactory method of preserving the foaming properties of the fresh clover was by deep freezing. Any procedure which included drying destroyed these properties and denatured the soluble protein.

An analysis was made of the organic-acid and soluble-sugar levels in bloating and non-bloating clover.

INTRODUCTION

Bloat is a confusing entity in which both plant and animal factors play a part (Johns 1956). It is the result of interference with the elimination of gas which is normally produced by the microbial fermentation of food in the rumen and reticulum. The malady as it occurs on pasture is usually associated with the grazing of legumes, though cases of bloat do occur on grass alone (Reid and Johns 1957). Bloat outbreaks are characterized by the sporadic and unpredictable nature of their occurrence, together with a day-to-day variation in the degree of severity. Apart from any change in animal susceptibility, it appeared that there may be some rapid changes in the balance of plant constituents in relation to the bloat-producing ability.

The chemical make-up of the herbage is obviously important, if only from the fact that the amount of readily fermentable substances in the plant will affect the rate of gas production in the rumen and reticulum. In addition to this, the physical state of the herbage may influence the conditions in the rumen by its effect on the degree of stimulation of saliva flow (Weiss 1953, Balch 1954).

Besides the readily fermentable plant constituents such as soluble carbohydrates and organic acids, the plant factors or their fermentation products incriminated from time to time in the production of bloat include: the cyanogenetic glucosides of white clover, histamine, anti-choline esterases, smooth-muscle-inhibiting flavones, nitrates, ammonia, ammonium carbamate, hydrogen sulphide, and saponins. A number of these compounds have been considered to cause bloat by the inhibition

of rumen movement, or the eructation mechanism, or by causing systemic poisoning. Though the more obvious effects of distension could obscure sublethal poisoning, Quin (1943), Johns (1954), and Reid and Johns (1957) believe that foaming of the rumen contents is the primary cause of the animal being unable to eructate efficiently.

In the first paper in this series (Johns 1954), it was suggested that there are at least three possible sources of foam-producing agents in the rumen: (1) saliva, (2) saponins, and (3) proteins and their breakdown products. More recently Hungate *et al.* (1955) have postulated that extracellular bacterial polysaccharides may play a part. Mangan and Fraser (unpublished) have also considered the possibility that the balance of foaming and antifoaming agents in the plant may be important in the aetiology of bloat.

Chemical methods for determining the concentration of foaming and antifoaming constituents of pasture plants are not available for the routine handling of a large number of samples. Hence an attempt has been made in the present paper to devise an empirical test for determining the foaming properties of various clover fractions and see whether there was any correlation with the bloating potency of the clover.

METHODS

Clover (Trifolium pratense and T. repens)

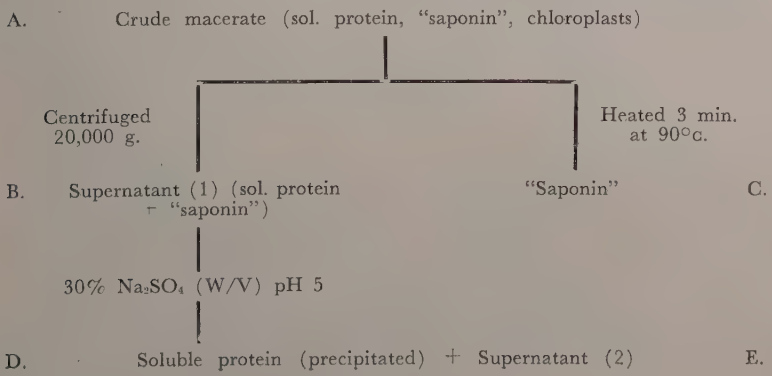
The clover was grown in pure stands and fresh samples were taken from the material that had just been cut for stall feeding to cows.

Feeding

The testing of the bloat-provoking properties of the cut red clover was carried out as described by Johns (1954) and the same system of grading employed. The bloat-susceptible twin pair of cows 293 and 294 were used over the four-month period of the trial together with 2 to 4 other bloat-susceptible animals. The bloat gradings recorded are the average for the particular day.

Preparation of Clover Extracts for Chemical Analysis and Foam Determinations

Fresh clover (100 g.) or 10 g. freeze dried + 200 ml 0.2M sodium acetate was ground in an end-runner mill with sand for 15 min. at



2°C., squeezed through muslin, and the residue washed with water to give a crude macerate. This was fractionated as shown below to separate compounds whose variations in concentration were likely to be significant in the aetiology of bloat. The fraction termed "saponin" was expected to contain this class of compound but might also contain unknown substances.

The fractions prepared as above were subjected to the analyses outlined below.

Foaming determinations were made on fractions A, B, and C by the serial-dilution method described below: Nitrogen was estimated in fractions A, B, and D by the micro-Kjeldahl method of Chibnall *et al.* (1943) after a preliminary macro-scale digestion. Fraction E was cleared by the method of Doak (1939) and the sugars estimated before and after hydrolysis with 0.15N H_2SO_4, by the method of Fujita and Iwatake (1932).

Fraction E was also analysed for total organic acids by the following method (Bathurst, pers. comm.): One millilitre of extract was placed on a column of Amberlite IRA-400. After washing thoroughly with water, the organic acids were eluted with 100 ml. of N ammonium carbonate. The eluate was boiled until the odour of ammonia could no longer be detected, and after cooling was passed through a column of Amberlite IR–112. The eluate from this column, together with the washings, was evaporated to dryness, taken up in a small quantity of water, and re-evaporated. This was repeated four times to remove volatile acids. The free organic acids were then titrated with 0.02N NaOH using phenolphthalein as indicator, and calculated as malic acid.

Estimation of Foaming Properties of Extracts

The foam stability of the above extracts (A, B, and C) was estimated by a serial-dilution method using digitonin as a reference standard. The lowest concentration of digitonin which will give a foam lasting one hour after shaking in a test tube was found to be 5.125 mg./100 ml. Hence the extracts were diluted serially (as described below) and the lowest dilution in the series which gave a foam lasting one hour was taken as having a foam stability equivalent to a digitonin solution containing 5.125 mg./100 ml.

It has been shown by a separate method (Mangan in preparation) that red-clover saponin has a maximum foam stability at pH 4.5 to 5.0 while that for cytoplasmic protein is at pH 6. The salt concentration is also important in the foaming properties of the protein (Mangan *loc. cit.*) so that all determinations of protein foaming were done in 1% sodium chloride.

Four series of dilutions were made as follows:

(1) Protein + saponin + chloroplasts at pH 6 in 1% NaCl.
(2) Protein + saponin pH 6 in 1% NaCl.
(3) Saponin pH 5
(4) Saponin pH 6 in 1% NaCl.

Digitonin equivalent (2)–(4) = foaming of protein at pH 6 in 1% NaCl.

Procedure: Pyrex test tubes (6 × ¾ in.) of uniform diameter were selected and cleaned before use with chromic-sulphuric acid, thoroughly washed with water, rinsed with distilled water, and dried in an oven. Ten tubes, fitted with clean rubber bungs, were set up in a rack. The first tube contained 25ml. of extract and the remaining tubes 5 ml. of water. From the first tube, 20 ml. was pipetted into tube 2 and the contents mixed without foaming: Then 20 ml. was transferred from tube 2 to tube 3, mixed, and so on down the series. Each tube then had ⅘ the concentration of the previous tube. To each was then added an additional 1 ml. of solution—in the case of 1, 2, and 4, 1 ml. of 6% NaCl. and with 3, 1 ml. of acetate buffer pH 5.0.

The tubes were stoppered and shaken vigorously with a vertical movement for 15 sec. The rack of tubes was then left undisturbed for one hour. The last tube to retain a complete cover of foam over the surface of the liquid (similar to 5.125 mg./100 ml. of digitonin) was taken as the equivalence point.

Calculation: The plant extracts were used for the dilution series either undiluted, or diluted 1:10 or 1:50, according to the foaming properties of the extracts. A table of dilution factors for each tube was constructed. Under these conditions, where 50 g. of plant material was extracted into 150 ml. of buffer, the results were calculated from 0.015375 × tube dilution factor = digitonin equivalent/100g. clover.

RESULTS

Effect of Wilting and Oven Drying on Foaming Properties of Red-clover Constituents

Owing to the number of determinations that had to be made in the trials, it was important to know whether the clover had to be used fresh, or could be oven dried or left to wilt.

A sample of clover was taken and divided into three portions: (a) was extracted fresh; (b) wilted overnight and extracted; (c) oven dried in a stream of air at 160°F. and extracted. The foaming properties of the various extracts were estimated by the serial-dilution method and the results are given in Table 1.

TABLE 1. FOAMING PROPERTIES OF EXTRACTS OF FRESH, WILTED, AND DRIED CLOVER EXPRESSED AS GRAMMES OF DIGITONIN EQUIVALENT/100g. DRY WEIGHT

	Clover		
	Fresh	Wilted	Oven Dried
Crude macerate pH 6	3.51	1.44	0.02
Protein + saponin pH 6	2.81	1.80	0.01
Saponin pH 5	3.51	1.44	0.10

It can be seen from Table 2 that oven drying very drastically reduces the foaming properties of the clover extracts made subsequently, while wilting has a considerably smaller effect.

Effect of Freezing and Freeze Drying on Cytoplasmic Proteins

As oven drying drastically affects the foaming properties of clover constituents, the effect of deep freezing and freeze drying the material were tried as possible methods of preserving this unchanged. It was felt that the component of interest most likely to be affected was the cytoplasmic protein as denaturation of this would affect its foaming properties. Hence estimation of the amount of this soluble constituent and the other nitrogen fractions were made after the clover had been subjected to various treatments as set out in Table 2.

TABLE 2. The Effect of Freezing and Freeze Drying on the Nitrogen Fractions of Red Clover

Clover Treatment	Total N in Fractions as % of Dry Matter				
	Total	Total Soluble	Cyto-plasmic Protein	Non-protein	Chloro-plastic
Fresh clover	4.48	3.08	2.56	0.52	1.40
Fresh clover deep frozen	„	3.04	2.51	0.53	1.44
Fresh extract, freeze dried	„	3.04	2.49	0.55	1.44
Extract stored—deep freeze for 7 days	„	2.98	2.42	0.56	1.50
Clover freeze dried fresh	„	1.60	0.88	0.72	2.88
Freeze dried clover after storage deep frozen	„	2.17	1.48	0.69	2.31

It is obvious that any process that involves drying of the clover, brings about a denaturation of the cytoplasmic protein, which appears in the insoluble chloroplastic protein fraction. However, the deep freezing of either the clover or its extracts have not brought about denaturation, nor has the freeze drying of the extracts. These latter were well buffered, in contrast to their environment in the dried whole plant. Hence deep freezing of the fresh material appears to be a satisfactory method of preserving the solubility of fresh-clover cytoplasmic protein, whereas freeze drying does not. In the present work fresh clover was used for all foaming determinations.

Relationship between the Bloat-producing Properties of Clover and the Foaming Characteristics of the Various Extracts

Clover was fed to cows on some 70 occasions when foaming determinations by the serial-dilution method were made at the same time. A summary of the results is given in Table 3.

In none of analyses of variance did the differences between bloat grades approach significance level, and there were no significant differences between samples producing bloat and those not doing so. However, when the same data were calculated on a dry-matter basis (Table 4) this was not the case.

TABLE 3. RELATIONSHIP BETWEEN BLOAT GRADE AND FOAMING CHARACTERISTICS OF CLOVER. MEAN VALUES AND STANDARD ERRORS EXPRESSED AS DIGITONIN EQUIVALENT ON A FRESH-WEIGHT BASIS

Bloat Grade	Crude Macerate	Protein and Saponin	Saponin pH 5	Saponin pH 6
0	1.69 ± 0.11	1.41 ± 0.09	2.20 ± 0.15	0.90 ± 0.04
I	1.59 ± 0.25	1.39 ± 0.24	2.71 ± 0.33	1.01 ± 0.06
I–II	1.68 ± 0.28	1.17 ± 0.30	2.55 ± 0.39	0.90 ± 0.07
II	1.88 ± 0.21	1.66 ± 0.20	2.35 ± 0.28	0.99 ± 0.06
II–III	2.20 ± 0.33	1.44 ± 0.30	2.20 ± 0.44	0.91 ± 0.08
III	1.64 ± 0.23	1.48 ± 0.24	2.58 ± 0.31	0.90 ± 0.06
Mean squares & Results of F tests:				
Between grades	0.21 NS	0.14 NS	0.45 NS	0.02 NS
Within grades	0.44	0.28	0.76	0.02

TABLE 4. RELATIONSHIP BETWEEN BLOAT GRADE AND FOAMING CHARACTERISTICS OF CLOVER EXPRESSED AS DIGITONIN EQUIVALENT ON A DRY-MATTER BASIS

Bloat Grade	Crude Macerate	Protein and Saponin	Saponin pH 5	Saponin pH 6
0	9.99 ± 0.69	8.34 ± 0.61	13.59 ± 1.06	6.13 ± 0.36
I	11.98 ± 1.50	10.62 ± 1.52	18.31 ± 2.50	7.82 ± 0.50
I–II	14.14 ± 1.77	10.40 ± 1.96	21.81 ± 2.73	7.84 ± 0.57
II	12.49 ± 1.25	10.02 ± 1.28	16.11 ± 1.93	7.39 ± 0.50
II–III	16.48 ± 1.98	10.38 ± 1.96	18.86 ± 3.06	7.23 ± 0.67
III	12.69 ± 1.50	11.49 ± 1.70	19.55 ± 2.31	7.49 ± 0.55
Mean squares & Results of F tests:				
Between grades	73.2**	13.4 NS	102.7*	3.6 NS
Grade O v Rest	163.6**	61.2*	392.9**	17.2**
Within grades	15.7	11.6	37.4	1.8

From the analyses in Table 4 on a dry-matter basis, there was a significant difference between bloat grades in the foaming of crude macerate and of saponin at pH 5. However, as digitonin equivalent for bloat grade O was lower for each fraction than the other grades, this was tested in the analysis of variance. In each case there was a highly significant difference between Bloat Grade O and the mean of the remaining grades. That is, when the samples are classified into those producing bloat and those not producing bloat, there is a significant difference in all characters, Crude Macerate, Protein and Saponin, Saponin pH 5 and Saponin pH 6 when computed on a dry-matter basis.

The dry matters of the original clover samples were examined in an analysis of variance. This gave a highly significant F of 4.27 (for 6,60 d.f.). When the test is made of Bloat Grade O against the Rest, the F value rises to 18.98 (for 1,60 d.f.). Hence there was a highly significant difference between the dry matter of the samples producing bloat and those not doing so.

The means were:

Grade O	(33 samples)	17.2 ± 0.6%
Grade (I–IV)	(34 samples)	13.6 ± 0.6%

This appears to explain adequately the difference in significance of results of Table 3 and Table 4. There appears to be no relationship between the degree of foaming of the plant extracts as determined by the serial-dilution method and the degree of bloat when account is taken of the dry matter effect.

TABLE 5. CONCENTRATION OF SUGARS AND ORGANIC ACIDS IN RED AND WHITE CLOVER EXPRESSED AS PERCENTAGE OF DRY MATTER

Red Clover

Date	State of Animals	Total Sugars	Reducing Sugars	Organic Acids	Dry Matter %
11.4.56	No bloat	4.52	3.57	2.8	16.2
27.4.56	Bloat	5.56	3.44	3.4	12.5
30.5.56	Bloat	4.14	3.78	2.8	11.4
14.6.56	Bloat	5.48	4.17	3.4	11.5

White Clover

11.5.56	Bloat	5.79	4.79	3.5	16.8
15.5.56	No bloat	4.48	3.83	3.1	13.0
16.5.56	Bloat	7.48	5.91	3.0	13.0
22.5.56	Bloat	5.31	4.30	3.1	10.5

Comparison of Level of Soluble Sugars and Organic Acids in Bloating and Non-bloating Clover

These compounds are likely to be the most rapidly fermented plant constituents in the rumen giving rise to gas evolution. Hence it was of interest to see if they were present in greater concentration in clover that gave rise to bloat in cows than in non-bloating materal. Results of a number of analyses are presented in Table 5.

It will be seen that although, in general, bloating clover is associated with the higher concentrations of sugars and organic acids, it is not invariably so. There are not enough samples, particularly of the no-bloat material, to permit any definite conclusions.

DISCUSSION

The sporadic and unpredictable nature of bloat outbreaks cause the farmer considerable anxiety. It would be of considerable help if bloat-potent herbage could be characterized, if only by an empirical test. A number of workers have attempted to correlate the foaming properties of plant extracts with bloat, or studied variation in the foaming properties.

Weiss (1953) tried shaking samples of expressed lucerne juice each day over a period of months and found no significant variation in the amount of foam produced. Ferguson and Terry (1955) made a survey of some 50 herbage samples from fields on which bloat occurred. The samples were dried and examined for foaming capacity by a hot-water-extraction procedure. No correlation with bloat could be seen. However, they later showed, as was found in the present work, that oven drying of the herbage markedly reduced the foaming capacity of the fresh material. They also point out that Lindahl *et al.* (1954) have used dried material in the preparation of lucerne saponin for bloat trials. In view of the results of Ferguson and Terry, and of the present work, the use of dried material appears undesirable if the foam-producing components are to be extracted unchanged. The use of deep-frozen herbage appears to be the only satisfactory way of preserving the properties of the fresh material.

Ferguson and Terry (1955) extracted the juice of lucerne in a triple-roller sugar-cane mill and remarked that the foam formed was frequently an embarrassment. They state: "Experience showed that the frothing capacity of the juice at preparation gave a fair indication of its bloating potential. Red-clover juices, which were relatively innocuous, gave less foam, and grass very little, although one grass sample taken from a field in which grazing cattle had developed bloat gave a strong foam."

Though there was no association between the foaming tests carried out in the present work and the bloat potency of the clover, it could be that the procedure was at fault. It has been observed (unpublished results) that chloroplasts centrifuged down from the rumen ingesta have antifoaming properties. Hence it was expected that the centrifuging of the crude extract would lead to an increase in digitonin equivalent of the resulting supernatant over that of the whole extract. That this did not occur may be due to the grinding with sand in the end-runner

mill being more drastic on the chloroplasts than the method of their release from plant material into the rumen. The roller-mill extraction procedure of Ferguson and Terry is probably not as severe as the grinding with sand.

In the feeding experiments of Johns (1954) there was an association of increasing severity of bloat with the lower dry-matter content of the herbage, as was shown in the present work. However, at that period, of the two animals used continuously in the present experiment, cow 294 showed no significant increase in bloating severity with lower dry-matter content of the clover, while with 293 it was significant only at the 10% level. Thus there is not only a between-animal difference in the relationship of dry-matter intake and bloat but also a difference in the same animal at different periods.

The onset of bloat on pasture can be extremely rapid (15–20 min. after start of eating). It appears logical to assume that a supply of readily fermentable substrate must be available to the rumen microflora for the rapid production of gas and volatile fatty acids. The latter contributes by lowering the pH (unpublished results indicate that the pH must fall below 6.3 for stable foam formation). In addition the lowering of the pH produces extra gas by the release of CO_2 from the saliva.

Quin (1943) believed that acute bloat is associated with the rapid fermentation of sugar, mainly by yeast cells, and the retention of the resulting gas in the ruminal mass through the formation of foam. He believed that there was a correlation with the sugar content of lucerne and the severity of bloat. Henrici (1952) on the other hand, was unable to show any correlation between the carbohydrate composition of lucerne and its tendency to produce bloat. The results in the present paper are rather inconclusive, owing to the small number of samples analysed. However, the level of soluble sugars recorded here, and in other work from this laboratory, indicate that they are low by European standards, e.g. Jarrige (1954) clover 5–18% of total soluble sugars.

Rosen *et al* (1956) studied a soluble fraction of legume juice which gave rise to a rapid evolution of gas when added to rumen liquor in Warburg vessels. They identified this fraction as containing organic acids—malic, malonic and citric. They suggest that the bloat-provoking power of lucerne may result from the relative abundance of these substrates available for microbial decarboxylation. In the present work it does not appear that there is any greater quantity of organic acids in the bloat-producing clover than in the non-potent clover. Moreover, the levels reported here are low compared with some values reported in the literature for legumes by 6–8% (Fauconneau and Jarrige 1954), 11.6% (Ferguson 1948).

The apparent lack of correlation of sugar and organic acid level with bloat may mean that their levels are high enough to produce enough gas and volatile fatty acids to give rise to bloat when the complication of foaming is also present. It appears likely that, as bloat is such a complex entity, with both plant and animal factors playing a part, correlation of carbohydrate content with bloating would only be observed within a certain concentration range and provided all other factors are optimal. It is germane to the present reasoning to recall that in the trials of Johns (1954) there was a lower dry-matter intake of clover in cases of severe bloat than when no bloat occurred.

It appears to the authors that the difference between bloating and non-bloating herbage is unlikely to be due entirely to any difference in concentration of particular substances in the herbage. The cursory chewing that the animal gives the ingested herbage will result in only a portion of the cells being ruptured to release both the foaming and fermentation substrate materials into the rumen. It seems probable that this will be the most likely method of release of plant constituents within the first 15–20 min. The degree of maceration by chewing of the plant material is probably related to its succulence. Hence the physical condition of the herbage may play as important a part in determining the amount of the substances of interest being released into the rumen as their concentration in the plant.

It could be that a fault of the present method of making extracts is that the grinding procedure is much more severe than maceration by the cow and releases all the soluble plant constituents. Though the findings in this paper are negative, further work is obviously desirable to test these hypotheses.

ACKNOWLEDGEMENTS

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BORDER LEICESTER CROSS EWES FOR FAT-LAMB PRODUCTION

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Summary

Comparative production records of groups of approximately 170 Corriedale, 170 first-cross Border Leicester × Corriedale and 90 first-cross Border Leicester × Merino ewes have been obtained from 1952–56 inclusive. Since 1950, matings of Corriedale ewes with Corriedale and Border Leicester rams were made so that approximately 40 two-tooths of each type entered the ewe flock each year from 1952 onwards. The Border Leicester × Merino ewes were bred in 1951 and 1952 only. The three groups were at all times reared, mated, and run together in one mob. They were mated each year to Down rams and managed for fat-lamb production.

The following results for age balanced flocks have been obtained:

(1) The Border Leicester × Corriedale (BL.C) ewe lambs are 9lb. heavier at weaning, grow faster as hoggets, and are 15–20 lb. heavier at maturity than the Corriedales.

(2) The BL.C ewes clip 0.9 lb. more wool per ewe than the Corriedale but the wool being of 48/50s count in comparison with 56s loses in value 10% per pound so that financial returns per fleece are approximately equal.

(3) The BL.C ewes are much more fertile than the Corriedales, dropping 23% more lambs per ewe lambing, and weaning 23% more lambs per ewe mated.

(4) The weaning weights of both single and twin lambs from the BL.C ewes are 5–6 lb. higher than those from the Corriedales.

(5) The BL.C ewes give a higher percentage of lambs fat off the mothers, with 1.7 lb. higher carcass weight and of a slightly better conformation.

(6) The financial returns per ewe from the BL.C exceed those from the Corriedale by 29% for lamb only and by 16% for lamb plus wool.

(7) The Border Leicester × Merino ewes clip the same weight of wool of approximately the same value as the Corriedale. Their fertility and lamb growth rate are intermediate between the BL.C and the Corriedale, giving financial returns 17% higher than the Corriedale for lamb alone and 10% for lamb plus wool.

Breeding systems required to provide first-cross ewes for fat-lamb production are discussed.

INTRODUCTION

Crossbreeding plays a most important part in fat-lamb production. It has long been recognized as conferring distinct advantages in quality, rate of maturity, and ease of fattening of the crossbred lambs by comparison with purebred lambs, and it finds expression in the almost universal use of Down rams over longwool ewes. The ewes employed in fat-lamb raising are usually the surplus breeding ewes from areas of relatively unimproved land such as hill country or extensively grazed country, where the main source of income is from wool and surplus store stock. On a national basis fat-lamb production and store-sheep production on hill country are inter-related to mutual benefit.

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In New Zealand, the sheep industry is organized on a very simple plan which for want of a better name will be called the two-tier system. The same breed of sheep, whether it be Romney or Corriedale, is used on both the hill country and the lowland fat-lamb country. The ewes are bred and reared on the hills and then sold down-country either as surplus two-tooth or cast-for-age ewes to the fat-lamb producer who crosses them with a Down ram, all the progeny being fattened and slaughtered. This stepwise organization of hill-country purebreeding flocks and lowland fat-lamb flocks crossed with Down rams forms the two tiers. Such an organization has advantages of simplicity and of uniformity in the wool and lamb grown, and it takes advantage of crossbreeding in the final stage through the use of Down sires; but it has at least one possible disadvantage that the breed of sheep reared on hill country may not be the most suitable for subsequent use in the lowland environment. This is particularly evident when the level of per-ewe production, especially in respect to lambing percentage and lamb growth rate is considered in relation to the very favourable environment obtaining on fat-lamb farms.

The New Zealand two-tier system employs purebred (or virtually purebred) ewes as the dams for fat-lamb production. The attainment of a higher level of production through the use of crossbred ewes is a possibility that has never been tried. If crossbreeding on the dam side, as distinct from crossbreeding with Down rams in the final stage to produce the fat lamb, is to succeed, it is fairly clear that the greatest scope for improvement would lie in rectifying the generally low lambing percentage and slow lamb growth rate from the existing purebred Romney and Corriedale ewes, through crossing them with a breed of high fertility and milk production to give as many first-cross breeding ewes as possible.

The use of first-cross ewes automatically introduces an extra stage into the organization thus giving a three-tier system, constituted as follows:

(i) a hill country purebreeding flock, e.g., Romney rams on Romney ewes

(ii) a crossing flock on intermediate country (foothills or downs) in which the surplus purebred ewes from the hill-country flock are crossed with sires of a high-fertility breed, e.g., Border Leicester ram on Romney ewe, in order to produce first-cross female progeny for sale as ewe lambs or two-tooths, and

(iii) a fat-lamb flock on the highly improved lowland country in which first-cross ewes are purchased as ewe lambs or two-tooths from the second-tier crossing flock and these ewes are crossed with a Down sire, e.g. Southdown ram on first-cross Border Leicester × Romney ewe.

Any study of the relative merits of first-cross and purebred ewes in fat-lamb production must also give due consideration to all the alterations in the sheep industry which are involved in changing from a two-tier to a three-tier system.

Precedents for the use of a three-tier system already exist in certain other sheep-producing countries. For example, in Scotland, Blackface and Cheviot hill ewes are crossed with the Border Leicester ram to

give the Scotch greyface and halfbred respectively and these first-cross ewes are then mated to Down rams. In Australia the unsuitability of the Merino as a fat-lamb dam has necessitated crossing it with the Border Leicester and Dorset Horn to produce crossbred ewes for subsequent mating to Down rams. In the north of England the Wensleydale is used as the high-fertility sire; in the United States, the Suffolk and Hampshire.

Crossbreeding in fat-lamb production under New Zealand conditions has been the subject of prolonged investigation over the past ten years at this College. It has resolved itself into separate studies of first the sires and then the dams in the final stage of production. The relative characteristics of the lambs produced by the different breeds of sire, and particularly by the Down breeds, have already been published (Coop and Clark 1952, 1957). These sires would be common to both the two and the three-tier systems. The study of dams for fat-lamb production is the concern of this present paper. The investigation to be reported covers a comparison of the productive characteristics of first-cross and purebred ewes when crossed with Down sires, and the consequences that arise from the use of the first cross ewes in place of purebred ewes, namely the change from a two-tier to a three-tier system

Experimental Methods

Choice of Breeds

The first consideration in a study of crossbreeding and the three-tier system is that of the breeds to be used. The basic hill breeds in New Zealand are the Romney and the Corriedale*. The first tier must be constituted of purebreeding Romney or Corriedale flocks. Because of the ready availability of a fairly large Corriedale flock belonging to the College this breed was adopted as the base.

The next problem is that of the breed of ram to use in crossing over the hill breeds to produce the first-cross ewes. Since wool remains a most important commodity in our economy even on fat-lamb farms, the choice is narrowed down to those breeds of high fertility producing a reasonably good weight and quality of wool and having white faces. From the short list of breeds that might meet these specifications—Border Leicester, Cheviot, Dorset Horn, and Wensleydale, the Wensleydale was excluded because it was not available in the country, the Dorset Horn because of a probable loss of fleece weight and the Cheviot because of the recognized loss of fleece weight (Peren *et al.* 1951: Phillips 1951). It was decided therefore that the Border Leicester would be used, though this does not exclude the possibility that other breeds might have virtues worthy of exploitation.

The breed of Down ram to be used in the final stage is relatively immaterial, provided the same breed is used in both systems, since the comparison is basically one of ewe productivity.

In connection with the breeds, it is appropriate to list the comparative characteristics of the College Border Leicester and Corriedale stud flocks on which the experimental flocks were largely based, and also

*For the sake of simplicity the New Zealand halfbred is considered as equivalent to the Corriedale.

of the Romney stud, all three of which are run together as mixed-age flocks in the one environment, but bearing in mind that that environment is unlikely to be equally suited to all three breeds.

	Border Leicester	Corriedale	Romney
Ewe fleece weight (lb.)	9.10	9.43	9.95
Ewe fleece count	44/46	56	48/50
Fertility	1.70	1.47	1.59
Twin-lamb growth rate (lb./day)	0.60	0.53	0.50

Fleece weight does not include bellies and crutchings, and fertility represents lambs born per ewe lambing, both being ten-year means. Twin-lamb growth rate is the daily gain to 60 days of age, the mean of the last two years.

Another consideration is that of relative age composition of the flocks. Under existing conditions in New Zealand, there are three types of fat-lamb flock (i) those maintained by the purchase of cast-for-age ewes and hence having aged ewes only, (ii) those maintained by purchase of two-tooth ewes and therefore having an age balance and (iii) those self-maintained by breeding their own replacements and therefore being age balanced. Under the three-tier system, cull two-tooth and cast-for-age purebred ewes go into the second tier or intermediate crossing category. The fat-lamb producer in the third tier purchases first-cross ewes either as ewe lambs or two-tooths and hence must possess an age-balanced flock. Consequently in this study emphasis has been placed upon comparison of productivity in age-balanced flocks.

Experimental Flocks

The experiments were carried out on the Ashley Dene farm of Lincoln College. This is a self-contained fat-lamb farm breeding its own replacements and therefore well suited for a comparison of the three-tier and two-tier systems, since the typical New Zealand two-tier system was already in operation on the farm. Furthermore, it represented a cross-section of the New Zealand sheep industry since it contained both a breeding flock and a fat-lamb flock, with surplus ewes from the breeding (or replacement flock) being supplied to the fat-lamb flock. The farm itself is one of 880 acres of light land, comprising 700 acres of 4–10 in. of very stony, sandy and silt loam over deep gravel (Eyre series) and the remainder of 18 in. of shallow, sandy loam over deep gravel (Wakanui series). It carries normally 1,600 Corriedale ewes and 400 Corriedale replacement ewe hoggets. Of the 1,600 ewes about 850 of the younger and better-woolled ewes are put in the replacement

The experimental groups were as follows:

BL.C	Border Leicester × Corriedale
BL.M	Border Leicester × Merino
C.C	Corriedale × Corriedale (control)

flock mated to the Corriedale ram, and the remaining 750 ewes, comprising the aged and poorer-woolled ewes go into the fat-lamb flock. From mating or in some cases from weaning of lambs at four months of age, the three groups were at all times run together and so had identical treatment. They were all individually identified at birth by ear tag and all their progeny were similarly ear-tagged. Complete records of production were maintained.

The object was to breed age-balanced groups of 150–200 ewes, to achieve which about 40 ewes would be required to enter each group each year. In the event, the breeding of the groups was as follows: In 1950, Border Leicester and Corriedale rams were used over groups of 60 Corriedale ewes from the fat-lamb flock in a fat-lamb sire experiment. The 30–40 ewe lambs weaned from each of these groups were retained to enter the experimental flock. In 1951, a group of 300 Corriedale ewes from the replacement flock was halved at random and mated to Border Leicester and Corriedale rams. A line of 200 aged Merino ewes was purchased and mated along with the Corriedale ewes to the Border Leicester rams. These matings produced 70–80 ewe lambs for each of the BL.C, BL.M and C.C groups. In 1952 a further 40 ewe lambs of each group were bred from replacement Corriedale ewes and the Merinos. At this stage the remaining Merino ewes were sold. In 1953 and 1954, 30–40 ewe lambs were bred each year by Border Leicester rams out of fat-lamb flock Corriedale ewes (in a fat-lamb sire trial) and an equivalent number of pure Corriedale ewe lambs were taken at random from the main replacement ewe-lamb flock. From 1955 onwards, more than 200 BL.C ewe lambs have been bred each year along with 200 pure Corriedale ewe lambs but at the time of writing only the hogget data from these larger numbers are available.

The BL.C and C.C flocks were thus constituted of 30–40 two-tooths in 1952, increasing in numbers to 110–120 two-tooths and four-tooth ewes in 1953, to 130–140 two- four-, and six-tooth ewes in 1954, 150–160 two-tooth to four-year ewes in 1955, and finally to 170 mixed-aged (two-tooth to 5-year ewes) in 1956. These two groups always had approximately equal numbers in each age category. The BL.M ewes on the other hand were born only in 1951 and 1952, and consisted of 68 two-tooths in 1953 and 99 two- and four-tooths in 1954, thereafter declining to 80 in 1956. The wastage in these groups is higher than the mortality figures (see later) require. Ewes that lost their ear tags were excluded unless it was certain to which age category of which group the ewes belonged.

In connection with this breeding programme the following points are relevant:

(1) there was never any culling or selection of the sheep bred and all survivors remained in their groups;

(2) the Merino ewes were of the strong-combing Anama (South Australian) strain;

(3) the Border Leicester and Corriedale rams used were all from the College studs. They were ordinary flock rams and differential selection as between the two breeds was guarded against. The BL.C ewes were the progeny of 12 different rams and the C.C ewes the progeny of at least 16 rams.

Fig. 1.—Photographs of Border Leicester × Corriedale, Border Leicester × Merino, and Corriedale ewes. These ewes were not photographed at the same time of the year, and they carry 7 months, 12 months, and 10 months of wool respectively.

The main comparison in this study is between the Border Leicester × Corriedale and the pure Corriedale, but it was also decided to include a group of Border Leicester × Merino ewes to be compared with the control Corriedale group (Fig. 1). The reason for the inclusion of this group was in order to have sheep with the same wool type (56 count) as the Corriedale and possessing 50% Merino blood like the Corriedale but differing in being a first cross Border Leicester × Merino in comparison with the inbred Lincoln × Merino (Corriedale).

The combined flock of BL.C, BL.M and C.C ewes was subjected to the normal farm management and was treated the same as the rest of the Ashley Dene flock except that in 1955 and 1956 it was run on the heavier land of the farm from lambing until weaning. The ewe lambs and hoggets were invariably run with the main hogget flock. The combined experimental flock was mated each year to Down rams, to Suffolks in 1952 and 1954, Southdowns in 1953, and Southdowns, Dorset Downs, and Suffolks in 1955 and 1956. In the latter two years, each age category of each group was separately randomized to the three breeds of ram so as to avoid any sire effect.

During the first three years, the lambs were drafted and weaned in one operation, but in 1955 and 1956 two drafts were taken and the store lambs were weaned at the second draft. The two drafts were combined to calculate the number fat off the mothers. The second drafts were much smaller than the first and the errors involved in assessing the combined drafting percentage rather than the two separately would be of minor significance. First drafts were taken as early as at a mean age of 87 days in 1954 and as late as 111 days in 1953.

Terminology

Fleece weight—weight of fleece thrown on to the table—does not include bellies and crutchings.

Fleece count—the quality number on the Bradford Scale.

Fleece grade—classer's commercial grading scored AAA 7, AA 6, A 5, BB 4, B 3, C 2, D 1.

Barrenness—barren ewes as percentage of ewes mated.

Ewe mortality—ewes dying as percentage of ewes mated.

Lamb mortality—lambs dying as percentage of lambs born.

Lambs born—lambs born dead or alive as percentage of ewes lambing.

Lambs weaned—lambs weaned as percentage of ewes mated.

Weaning weight—actual live weight at weaning corrected to the mean age of all lambs weaned from all three groups.

Per cent FOM—number of lambs drafted fat off mothers (FOM) as percentage of total lambs present at drafting.

Prime FOM—number of prime grade lambs drafted as percentage of total lambs present.

Seconds—number of second grade lambs as percentage of those lambs drafted to the Freezing Works.

RESULTS

The results of the five years' study on the ewes are summarized in Table 1, giving the main features year by year as they occurred, bearing in mind that both age distribution and seasonal conditions varied from year to year.

TABLE 1. WOOL AND LAMB PRODUCTION 1952–1956

Year	Group	Fleece Weight	Lambs Born	Lambs Weaned	Weaning Weight Singles	Weaning Weight Twins	Percent FOM	Carcass Weight
1952	BL.C	8.2	126	61	68.3	—	41	—
	C.C	7.2	105	46	60.8	—	27	—
1953	BL.C	9.9	131	100	61.7	53.7	62	30.7
	BL.M	8.6	120	74	56.0	47.0	50	29.3
	C.C	8.7	121	84	55.0	48.4	47	29.0
1954	BL.C	9.2	153	124	67.0	54.5	60	33.7
	BL.M	8.5	135	101	65.0	52.4	54	32.0
	C.C	8.1	126	100	62.2	49.6	48	31.4
1955	BL.C	10.0	158	139	74.3	65.8	95	32.5
	BL.M	9.0	167	144	73.0	60.6	89	30.4
	C.C	8.8	142	122	68.1	58.7	81	29.7
1956	BL.C	9.6	159	138	76.7	66.5	84	35.1
	BL.M	9.0	150	135	75.3	66.2	86	34.9
	C.C	9.1	131	115	72.6	61.7	78	34.6

These results show that the BL.C ewes have out-produced the control C.C ewes by averages of 0.9 lb. in fleece weight, 19% in lambs weaned, 5½ lb. in weaning weight, 12% in lambs fat off mothers and 1.8 lb. in carcass weight. These figures do not necessarily represent the true comparison, as they are weighted heavily numerically on the side of the younger age categories as compared with the older ewes. It is now necessary to examine in more detail the various aspects and measurements made in the comparative study.

Growth and Development of Ewes

The live weights of the sheep have been recorded throughout the years, the hoggets at regular intervals and the ewes in the autumn just prior to mating. The observations are summarized in Table 2, which sets out the mean live weights over the whole period.

TABLE 2. MEAN LIVE WEIGHT (lb.) OF EWES ACCORDING TO AGE

	Weaning 4 months	12 months	1½ years	2½ years	Mature
BL.C	65	99	122	131	146
BL.M	47	89	110	121	137
C.C	56	85	104	114	131

This table shows that the BL.C ewe lambs at weaning have a 9 lb. advantage over the purebred C.C lambs and that this difference increases during the hogget stage and up to the two-tooth stage, thereafter remaining at the 15–20 lb. level. The BL.M lambs get a relatively bad start, being out of Merino ewes, but afterwards make satisfactory gains, eventually exceeding the C.C ewes by about 6 lb. at maturity. The possible effect of these live-weight differences on carrying capacity will be discussed later.

The rearing of replacements through the hogget stage from weaning at three to four months of age to the following spring at 12 months of age often presents difficulties. The greater live weight of the BL.C ewe lambs at weaning is important since it suggests that these lambs are stronger and less liable to suffer the set-backs associated with the hogget. The BL.C hoggets have in fact been easier to rear than the C.C. hoggets except that deaths in the autumn from enterotoxaemia are liable to be rather higher in the better-growing BL.C hoggets. In all except one year the hogget losses have been relatively light, about three per cent, with no overall differences between groups. In 1952, difficulties were experienced through failure of autumn growth and consequent lack of feed. In this year the losses were BL.C 4%, BL.M 10% and C.C 14%. Until 1955, the hoggets were not shorn as lambs, but from that date all lambs were shorn in January and again in October-November.

The greater live weight of the BL.C lambs at weaning, their greater growth rate as hoggets, and the fact that in average years they can be brought to 100 lb. live weight at 12 months of age, suggests that the difference might be exploited by mating the ewe hoggets. Through not wanting to interfere with the main comparisons of the trial, experimental matings were made on only a small scale but they were done in the years 1953, 1954, and 1955. These showed that from 25–70% of the BL.C ewe hoggets could be got to lamb by 10 October, which is about the latest date on which lambs are wanted on the farm, compared with 15–25% of the pure Corriedales. If Southdown rams are used, the BL.C ewe hoggets will wean lambs of about 50 lb. live weight, therefore mostly store lambs, at 90 days of age. This does indicate that in good years it would be profitable to breed from the BL.C ewe hoggets provided that their lambs are weaned early enough to allow the hoggets to recover in time for the two-tooth mating. It would scarcely be recommended with the purebred Corriedale lambs, since so few can be got in lamb in time.

The lambs produced, the effect on hogget wool, and any effect on subsequent production in those hoggets that lambed have been neglected. To take them into account would be to the advantage of the BL.C group.

Longevity

In 1955, it became apparent that the teeth of the older ewes were beginning to wear and to wear more rapidly in the BL.C group than in the C.C group. In the autumn of 1956 a few of the 5½-year BL.C ewes had to be culled for teeth and in February 1957 the teeth of all ewes were carefully examined and graded. This showed that only 15% of the original number of 6½-year BL.C ewes bred could be

retained for breeding in 1957, compared with 30% of the 6½-year C.C ewes. In the 5½-year ewes 80% of the BL.C group were retained and 100% of the C.C group. These observations are interpreted as showing that the BL.C ewes have on average about ¼ year less breeding life. If the average life of a Corriedale ewe on the Ashley Dene farm is five lambings, i.e. 6½ years, then up to 25% of the BL.C ewes would have only four lambings. In mixed-age flocks, therefore, there would be 25% fewer BL.C ewes in the oldest age category and a compensating higher number spread throughout all the lesser age categories. Since the oldest ewes are the best lamb producers, this must be taken into account in comparing mixed-age flocks of the BL.C and C.C groups, and this has been done in all subsequent analyses.

The higher replacement rate also means that for every 100 ewes in a mixed-age BL.C flock one extra two-tooth ewe has to be purchased and one extra old ewe sold, in comparison with a C.C flock.

Ewe Management

No particular differences have been observed in the relative resistance of the three groups to footrot, worm infestation, fly strike, and other conditions. The BL.C ewes are heavier to handle and because they grow longer wool they require more dagging than the shorter-woolled groups. On the other hand the BL.C (and BL.M) ewes are clear on the face and legs and so are easier to shear and crutch. The BL.C ewes are also easier to handle at lambing time, being quieter and more easily caught, and mothering their lambs better than the C.C ewes. They also make better foster mothers. The BL.M ewes, though quite good mothers, are wilder and not as easily caught as the C.C ewes under intensive lambing conditions.

Wool Production and Value

The annual fleece weight (shorn in November) (Table 1) has shown that the BL.C ewes clip nearly 1 lb. more than either the BL.M or C.C ewes. The data may alternatively be expressed by combining the same age categories in the different years to determine any differential age effects. This has been done in Table 3.

TABLE 3. MEAN ANNUAL FLEECE WEIGHT BY AGES

	1 year	2 year	3 year	4 year	5 year	6 year
BL.C	9.5	9.5	9.7	9.5	9.5	9.2
BL.M	7.6	8.3	8.9	9.1	8.7	—
C.C	8.5	8.5	8.7	8.7	8.9	8.6
BL.C–C.C	1.0	1.0	1.0	0.8	0.7	0.6

In this table, age is given as the age at shearing, thus the one-year fleece is the woolly-hogget fleece or the lamb plus shirl-hogget fleece and the four-year fleece is that from ewes 4¼ years of age. Weights at different ages are not comparable since the one-year fleece is the mean of six years whereas the six-year fleece covers only one year.

It will be seen that the BL.C fleece maintains the 1.0 lb. advantage for the first three years but that as the ewes age this difference decreases, demonstrating that the normal decline in fleece weight with age is greater in the BL.C than in the C.C ewe. On the other hand the decrease in grade of wool with age of ewe (not shown in table) does not appear to be any more severe in the BL.C than in the C.C ewe. This table also shows that the BL.M ewes, which get a worse start in life through being out of Merino ewes, clip a significantly lighter fleece at the hogget stage but thereafter fleece weight is almost identical with that of the C.C ewes.

The 1954 and 1955 fleece weights have been statistically analysed. This analysis shows a standard deviation of 0.07 lb., a coefficient of variation of 0.8%. The differences in fleece weight between the BL.C and C.C are highly significant ($P < 0.01$), between BL.C and BL.M highly significant ($P = 0.01$), and between the BL.M and C.C groups not significant.

During the last three years, when larger numbers had been bred and there was some age distribution, a more detailed analysis of the wool clip has been made. The wool from the three groups has been binned by a different wool store each year and sold in such a manner that relative prices of fleece wool and oddments may be obtained. These data are presented in Table 4.

TABLE 4. MEAN WOOL CHARACTERISTICS OF MIXED-AGE EWES 1954–1956

Year	Group	Fleece Weight	Length (inches)	Count	Grade	Price d/lb.	Fleece Value
1954	BL.C	9.19	—	49.0	3.1	52.0	41/0
	BL.M	8.46	—	55.0	2.9	56.2	40/5
	C.C	8.10	—	56.5	3.1	60.8	41/4
1955	BL.C	9.96	5.8	49.0	3.0	47.5	42/2
	BL.M	9.00	4.6	53.8	3.1	47.8	41/0
	C.C	8.85	4.4	56.4	2.9	49.5	40/0
1956	BL.C	9.56	5.4	49.4	3.3	54.8	47/10
	BL.M	8.98	4.5	54.9	3.0	57.4	47/2
	C.C	9.08	4.3	56.6	3.1	63.0	52/5

Before discussing these figures, it must first be stated that the price per lb. is that for both fleece wool and oddments and that the fleece value likewise includes both fleece wool and oddments, whereas the fleece weight quoted does not include the bellies and crutchings. Weights of bellies and crutchings have been found to be approximately the same (within 0.1 lb.) in the three groups. One might expect the clear-faced and clear-legged BL.C sheep would give a higher ratio of skirted fleece wool to pieces and necks than the C.C sheep, but the difference in favour of the BL.C in this respect is in fact very small and for all practical purposes negligible. Nevertheless, almost all of the fleece-weight differences recorded are in skirted fleece wool.

The BL.C wool is of the fine crossbred type with long staple, and the BL.M is classified as strong halfbred to fine threequarterbred with

only slightly greater staple length than the Corriedale. The fact that strong-combing Merino ewes were employed to breed these sheep has no doubt contributed strongly to the mean count being nearly two counts stronger than the pure Corriedale. The grade score shows that in the the classer's opinion the BL.C wool is at least as well grown for its type as is the C.C. An important feature of grade and also of price per pound is cotting. Very little cotting occurs in the finer wools and in the C.C group the mean percentage of cotted fleeces during the three years has been 3%. The stronger the wool the greater the tendency to cott, and this is well borne out in this trial, since the corresponding figures for the other groups were BL.M 8% and BL.C 18%. Part of the tendency to cotting is no doubt attributable to the higher proportion of twins reared, but nevertheless it is an important factor.

In the final analysis it is the financial return that decides relative value of the different types of wool. Table 4 gives the necessary details of these. This shows that in 1954 the extra weight of the BL.C wool has compensated for the lower price per pound; in 1955, owing to strong demand for crossbred wool, it has more than compensated, while in 1956 in which the weight difference was the lowest recorded, and with fine wools selling well, the weight did not compensate for lower price per pound. Taking the three years as they stand, they show that value per fleece from all three groups is of the same order, varying slightly one way or the other according to the relative commercial demand for fine wools and crossbreds.

Mortality

Records of ewe and lamb losses have been kept and are summarized in Table 5. Instead of summarizing the actual mortalities, the figures have been expressed as the mean of the age groups from two-tooth to 5½-year ewes, which is the true value for a mixed-age flock.

TABLE 5. EWE AND LAMB MORTALITY

	Ewe %	Lambs %
BL.C	1.2	9.9
BL.M	1.9	10.5
C.C	1.3	10.9

These differences are not statistically significant. The lamb mortality has been of the order of 15–20% from two-tooth ewes, and 3–10% from the old ewes. Although the BL.C ewes have more twins, for which a higher mortality might be expected, the better mothering and milking qualities of these ewes has more than compensated for any tendency towards higher losses. In the final analysis, the slightly lower losses in the BL.C group has meant that the percentage difference in lambs born has been maintained undiminished to the weaning stage.

Barrenness

The percentages of ewes that proved to be barren are given in Table 6.

TABLE 6. PERCENTAGE OF BARREN EWES

	Two-tooths	Old Ewes	Mixed Age
BL.C	12	3	4.7
BL.M	16	3	5.4
C.C	15	4	6.0

These figures again show a slight, non-significant advantage to the BL.C ewes, but it must be concluded that the percentage of barren ewes is not greatly reduced by crossing with the Border Leicester.

Prolificacy (Lambs Born)

The age distribution of prolificacy is shown in Fig. 2.

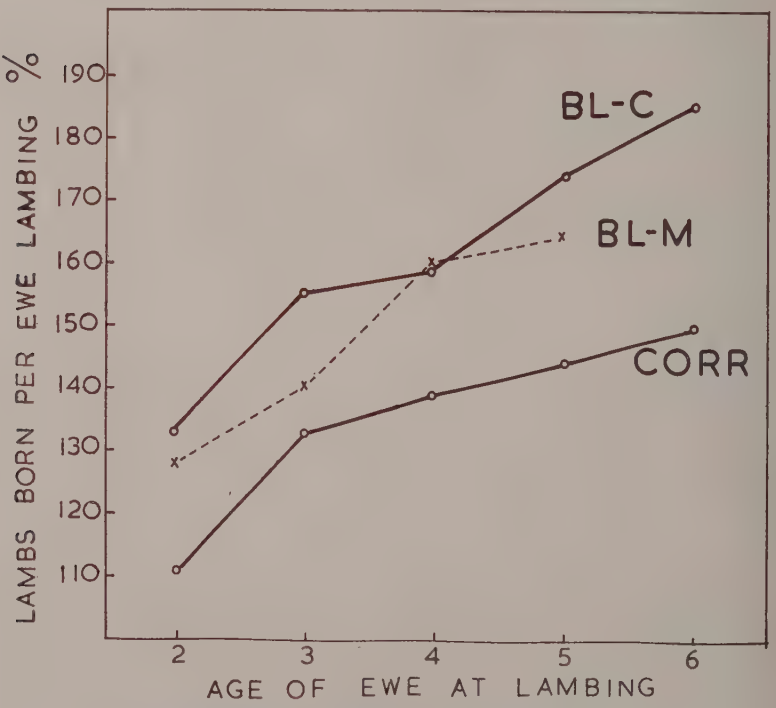

Fig. 2.—Age distribution of prolificacy of Border Leicester × Corriedale, Border Leicester × Merino, and Corriedale ewes.

It will be appreciated that the data from which these curves are obtained are derived from records of 200 two-tooths of each of the BL.C and C.C groups covering five years, 160 four-tooths during four years, decreasing to 25–30 in one year only in the oldest age category

(six years old at lambing). The curve for the pure Corriedale group approximates very closely to that obtained from the thousand or more other Corriedales on the Ashley Dene farm from which has been obtained approximately 10% of twin births in two-tooth ewes and 40–50% in ewes lambing at five and six years of age.

The BL.M curve shows a definite superiority over the Corriedale ($P < 0.01$) with a mean value of 17%. The BL.C curve also clearly demonstrates the enhanced prolificacy resulting from crossing with the Border Leicester. A consistent difference occurs at all ages, with a tendency for the difference to increase at the older ages. The mean superiority of the BL.C over the C.C for a mixed-age flock amounts to 25%, but bearing in mind that with such mixed-age flocks the BL.C must contain 25% fewer ewes in the oldest age category this difference is decreased to 23%. This difference is also very highly significant ($P < 0.01$).

Lambs Weaned

The weighted vital statistics for all years culminating in the percentage of lambs weaned per ewe mated in a mixed-age flock are given in Table 7. Again, allowance has been made for a lower proportion of BL.C ewes in the oldest age category and the performance of BL.M ewes lambing at six years of age has had to be estimated.

TABLE 7. PERCENTAGE OF LAMBS WEANED IN MIXED-AGE FLOCKS

	Lambs Born	Ewes Barren	Ewe Mortality	Lamb Mortality	Lambs Weaned
BL.C	159	4.7	1.2	9.4	136
BL.M	153	5.4	1.9	10.0	127
C.C	136	6.0	1.3	10.4	113

In comparison, the average percentage of lambs weaned from the remaining 1,200 mixed-age Corriedale ewes on the Ashley Dene farm over the years 1953–56 inclusive has been 109 per cent.

This table shows that in the final analysis of lambs weaned per ewe mated the BL.C group shows an increase of 23% and the BL.M an increase of 14%. Both of these differences are statistically highly significant. It should be remembered that these percentage increases depend on how they are calculated. The figure of 23% for the BL.C group based on ewes put to the ram is reducible to $23 \times \frac{100}{113} = 20\%$ when based on the number of lambs weaned by the Corriedale control group.

Lamb Weaning Weight, Percentage Fat off Mothers, Carcass Weight

The age-corrected weaning weights of the lambs have been given in Table 1. The age corrections were made between groups in the same year but not between years. The figures of Table 1 show that the weaning weights of both single and twin lambs are 5–6 lb. greater in the BL.C group than in the C.C group. This difference is fairly

constant at all ages so that taking a mixed-age flock does not materially alter the position. However, the results for the years 1954–56 inclusive have been combined to present the position in a mixed-age flock of 2, 4, 6, and 8 tooth ewes. The relevant data are summarized in Table 8. The live weights at first drafting have been subjected to between-year corrections to a mean age of 94 days. The actual mean ages at first drafting were 87, 95 and 101 days for the three years respectively.

TABLE 8. MEAN WEANING WEIGHT AND DRAFTING DATA 1954–1956

	Weaning Wt. at 94 days			All Lambs FOM (%)	Prime FOM (%)	All Lambs Carcass Weight	Primes Carcass Weight
	Singles	Twins	All Lambs				
BL.C	72.7	63.2	68.0	80	54	33.7	35.1
BL.M	71.1	59.8	66.2	76	48	32.7	34.5
C.C	67.6	56.7	64.7	69	43	32.0	33.4
BL.C–C.C	5.1	6.5	3.3	11	11	1.7	1.7

This table again shows that BL.C ewes wean lambs 5–6 lb. heavier than the C.C ewes if singles are compared with singles and twins with twins. Since the BL.C ewes wean more twin lambs which are approximately 10 lb. lighter than singles the mean gain on all lambs weaned is reduced to 3.3 lb., which represents a five per cent increase in live weight per lamb. The BL.M ewes occupy an intermediate position in this respect.

The growth rates as expressed by the age-corrected weaning weights of all lambs born in 1954 and 1955 have been analysed statistically. The standard deviation and coefficient of variation of weaning weight are 1.1 lb. and 1.6% respectively. The differences between the BL.C and C.C lambs are highly significant ($P < 0.01$) while those between the BL.M and C.C. lambs are significant ($P = 0.04$).

The drafting data are made on the lambs as they occur and not on age-corrected lambs. The mean ages of the BL.C and C.C lambs are practically identical, so that no particular correction or comment is called for, and the drafting data are strictly comparable between these two groups. However, the BL.M ewes have invariably taken the ram earlier and lambed earlier than the other two groups, with the result that at weaning these lambs are on average three days older. This naturally causes the percentage drafted fat and the carcass weights to be slightly better than would be expected from the age-corrected weaning weights. However the fact that BL.M ewes can be got in lamb early is a virtue and this group is therefore entitled to any gains thereby resulting.

Table 8 shows that in the control Corriedale group 69% of all lambs have been drafted fat off the mothers, the drafts containing 35–40% of seconds, leaving 43% prime lambs fat off the mothers. The superior growth rate of the BL.C lambs is reflected in 80% drafted containing 30–35% of second grade lambs and leaving 54% of prime lambs drafted fat off the mothers. This means that for every 100 lambs

present at weaning 11 more lambs are drafted fat and 11 fewer left as stores from the BL.C group compared with the C.C group.

The lambs drafted from the BL.C group are also heavier than those from the C.C group in carcass weight by more than 1½ lb. The BL.M lambs again occupy an intermediate position. The increased carcass weight of the BL.C lambs is a little over five per cent, but, owing to the present (1955–onwards) highly differential price schedule favouring light-weight lamb, the financial return is depressed by 0.2 pence per pound or by one per cent. Thus the net gain in financial return per carcass due to increased weight is about four per cent.

Carcass Quality

The fact that the lambs from the BL.C group have drafted well, giving both a larger proportion fat off the mother and higher carcass weights at the same age as those from the C.C group, indicates that they are at least as well finished and as high in quality.

In 1955 and 1956 detailed carcass measurements were made on all prime lambs and these are summarized in Table 9. In this table L represents length of carcass, G width of gigots, and F length of leg as defined by Palsson (1939).

TABLE 9. CARCASS MEASUREMENTS OF ALL PRIME LAMBS

Year	Group	Carcass Weight	L	G	F	G/F
1955	BL.C	34.9	567	225	243	0.929
	BL.M	33.5	558	221	242	0.914
	C.C	32.2	553	221	240	0.922
1956	BL.C	36.4	572	227	241	0.943
	BL.M	37.1	575	226	246	0.920
	C.C	35.7	570	224	242	0.929

The increased length of the BL.C lambs is in keeping with their higher weight and the G/F ratio which is the best single index of carcass conformation shows that the lambs from the BL.C group are at least as good as and probably better than those from the C.C group. As the higher weight of the BL.C might be the cause of their superior conformation the figures have been recalculated by excluding the heaviest BL.C lambs and the lightest C.C lambs to compare the groups under a system of equal carcass weight. This certainly reduces the superiority (1955—BL.C, 0.923; C.C 0.924. 1956—BL.C, 0.940; C.C 0.930) but does not eliminate it. Our subjective opinion is that the order of superiority of ewe carcass is C.C > BL.C > BL.M due largely to differences in length of leg. In the lambs, however, the faster growth rate of those out of the crossbred ewes enhances their conformation so that the order of lamb superority becomes BL.C > C.C > BL.M.

In 1956, six prime carcasses from each of the C.C and BL.C groups were selected. They were all sired by the Southdown ram and their weights were representative of the groups. The left hind leg and loin

of each carcass were dissected into fat, muscle, and bone; the cross-sectional length (a) and depth (b) of the longissimus dorsi muscle and depth of fat covering it (c) at the junction of the loin and thorax were measured as defined by Palsson (1939). The results are tabulated in Table 10.

TABLE 10. Composition of Leg and Loin from Lambs out of C.C. and BL.C Ewes

	Age (days)	Carcass wt. (lb.)	Leg			Loin			a	b	c
			Fat (%)	Muscle (%)	Bone (%)	Fat (%)	Muscle (%)	Bone (%)			
SD × C.C	104	32.2	18.4	67.2	13.8	44.5	46.5	9.0	49	28	4.6
SD × BL.C	105	34.3	21.4	66.0	12.8	43.1	47.9	9.0	51	26	5.3

These figures show that the BL.C lambs had more fat in the leg and less in the loin than the C.C lambs. There was considerable variation from lamb to lamb within each group and it is felt that the differences are not very significant. The biggest differences occur in the a, b, c measurements, which show that the longissimus dorsi muscle is better filled and has a thinner covering of fat in the C.C lamb than in the BL.C lamb in spite of the fact that the C.C loin contained less fat. One must conclude that either the distribution of fat is not the same in the two breeds or that an insufficient number of carcasses were dissected for consistent results to be obtained.

The relative carcass quality and financial return of the fat ewe slaughtered at the end of its breeding life has not been studied. This is not a very important consideration in relation to the lifetime output of the ewe, especially as any differences between groups in this characteristic are not likely to be large. One might expect that the BL.C ewe would kill out at higher weight and greater fat cover.

Assessment of Wool and Lamb Production

The ultimate assessment of any change in agriculture is in financial return and this must be used to check the results obtained. Comparing the BL.C group with the C.C group it has been shown that more wool is grown but the actual financial return per ewe is very slightly less. In lamb production, there are 20% more lambs each weighing 5% more, a total increase of 25%.

Table 11 gives the comparison of production per ewe for 1954–56 inclusive, using actual wool returns, actual lamb prices for lambs fat off the mothers, and an assumed value of 40/- per head for store lambs, which is the best estimate one can make of their true commercial value. The cost of fattening the store lambs is most difficult to determine accurately.

These figures show that on a per-ewe basis the financial returns from the BL.C group exceed those from the C.C group by 29% for lamb alone and by 16% for wool plus lamb. The BL.M group occupies the position halfway between the other two groups.

TABLE 11. ACTUAL AND RELATIVE FINANCIAL RETURNS PER EWE MATED

	BL.C	BL.M	C.C
Wool returns	43/8	42/10	44/7
Lambs weaned	1.36	1.27	1.13
Number lambs FOM	1.09	0.96	0.78
Value per lamb FOM	62/6	60/8	60/0
Number store lambs	0.27	0.31	0.35
Lamb returns	78/11	70/7	60/10
Relative lamb returns	129	116	100
Wool and lamb returns	122/7	113/5	105/5
Relative wool and lamb returns	116	108	100

DISCUSSION

The comparison of the Border Leicester × Corriedale with the pure Corriedale will be considered first. This shows that the Border-cross ewe produces nearly 1 lb. more wool per annum, but being of crossbred type it loses on value per lb. with the ultimate result that there is very little difference in total fleece value, the latter swinging in favour of one or the other according to the relative prices of strong wools and fine wools. There is a large and important difference in lamb production. The Border Leicester × Corriedale ewe weans 20% more lambs of 3–4 lb. higher weaning weight, giving 11% more fat off the mothers and an increase of 1½–2 lb. in carcass weight. On the basis of financial return, the Border-cross ewe gives a 29% increase in lamb production or a 16% increase when lamb and wool production are combined.

It is clear that the introduction of Border Leicester blood has increased fleece weight, fertility, and milk production (lamb growth rate). The increases are greater than one would expect from taking the mean of the Border Leicester and Corriedale stud flocks, and to this extent could be considered as an expression of hybrid vigour. However, this is a dangerous assumption and in our present state of knowledge no pretence is made of allocating the increased production to any particular factor such as the simple fact of introducing Border Leicester blood, hybrid vigour, or body size.

Commercially, the gains in production and financial returns are worthy of exploitation. The greatest drawback is likely to be on the score of carrying capacity. The Border-cross ewes are 13% heavier in live weight than the pure Corriedale ewe. For stall-fed animals this extra weight would increase maintenance requirements by 4% (Wallace 1948), 6% (National Research Council, U.S.A. 1945) 8% (Woodman 1952) and 9% (Brody, 1945). The effect of live weight in grazing animals is not known, but there is a suggestion that in grazing dairy cows (Wallace, 1956) maintenance requirements are more nearly proportional to body weight than is the case in stall-fed animals. This is an important point which remains to be clarified before comparison of

the Border cross and the purebred can be placed on a basis of relative food efficiency or carrying capacity. While this will no doubt reduce the overall gain below the 16% quoted, other factors are also important. In view of the very seasonal nature of grass growth and of the reliance which sheepfarmers place on grass for feeding, any factor that temporarily increases the number of stock during the period of excess growth in the spring and early summer leads to an increase in efficiency of pasture utilization over the whole year. Expressed in another way, the higher the lambing percentage, the better the equation of feed requirements of a breeding ewe flock to seasonal pasture growth. Hence the actual reduction in carrying capacity due to size of ewe could be less than would be indicated on the basis of maintenance requirement alone. Further, as some farm costs such as shearing are on a per-head basis, a smaller number of more productive ewes are more profitable than the other way round. Lastly, the ewe that gives a higher proportion of lambs fat off the mother has a special appeal, since not only are lambs fat off the mothers more economically produced but the labour and management of the farm is made easier. Finality in these matters cannot easily be reached.

The Border Leicester × Merino group was introduced into the trial mainly to give added evidence of whether the introduction of Border Leicester blood increases fertility. The Corriedale, with which it is compared, is an inbred Lincoln × Merino. Thus both groups have 50% Merino blood. Any differences between the groups may be due to either or both:

(a) the Border Leicester × Merino ewes being first cross and not inbred possess so-called hybrid vigour; or

(b) the superiority of the Border Leicester compared with the Lincoln blood.

The main feature of the trial as far as the Border Leicester × Merino group is concerned is that it is markedly superior to the Corriedale in fertility (14% more lambs weaned) whereas in the other features differences are relatively small. Again, one cannot distinguish between the two possible causes mentioned except that knowing the higher fertility of purebred Border Leicester flocks in comparison with Lincoln flocks it would be fair to claim that most of the difference between the Border Leicester × Merino and Corriedale groups is simply due to the introduction of the high-fertility Border Leicester blood.

In New Zealand, relatively few Merino ewes are sold down-country as surplus stock. Any such ewes are usually crossed with a Romney, English Leicester, or Lincoln ram to produce halfbreds. Our experiments strongly suggest that it would be considerably better to cross them with the Border Leicester, which is in agreement with current Australian trials (Sim and McCann 1950, Dep. Agric. Victoria 1954).

The main interest in the experiments is, however, in the Border Leicester × Corriedale cross, since the Corriedale is widely used both in this country and overseas. The superior production of the first-cross ewe calls for further examination of the whole breeding system. Taking first the case of the Ashley Dene farm, under the two-tier system approximately 50% of the Corriedale ewes are mated to Corriedale rams in the replacement flock, the remaining 50% of Corriedale ewes being mated to Down rams. If this is changed to the three-tier system:

(i) 25% of ewes, Corriedale mated to Corriedale rams in the replacement flock, breeding ewes for its own replacement and for

(ii) 25% of ewes, Corriedale mated to Border Leicester rams in the crossing flock, breeding ewes for

(iii) 50% of ewes, Border Leicester × Corriedale mated to Down rams in the fat-lamb flock.

The disadvantage of this system is that there are three instead of two flocks but they need be separated only during mating since the Corriedale, the Border Leicester × Corriedale, and the Down × (Border Leicester × Corriedale) are all readily identifiable by eye and they could, if necessary, be run in one flock at all other times of the year. The advantage of the system is that one obtains the gains already reported from the Border Leicester × Corriedale ewes and there are also gains in the crossing flock. In this flock, as in the replacement flock, wether lambs are sold either fat or as stores. The Border Leicester × Corriedale wether (and ewe) lamb grows faster and is much easier to fatten than the purebred lamb. Tests previously reported (Coop and Clark, 1952) in this connection show that whereas, for example, 30% of Corriedale wether lambs can be sold fat off the mothers, 60% of Border Leicester × Corriedale lambs can be drafted fat off the mothers, at 4 lb. higher carcass weight at the same age. It must be mentioned that in the two-tier system a considerable number of fat-lamb producers use cast-for-age ewes whose lamb production (but not wool) is naturally greater than that of mixed-age ewes. In the three-tier system all fat-lamb producers would have mixed-age flocks. To this extent the gains in fat-lamb production would be rather less than has been reported in the comparison of mixed-age flocks only. This would be counterbalanced nationally because the cast-for-age ewes with their higher fertility would then be used by those farmers in the second tier who breed the first-cross ewes. In other words the advantage of the cast-for-age would merely be transferred from one farm to another.

On a national scale, the same three-tier system could operate with the back-country hill farmer running the replacement flock and selling surplus breeding stock to intermediate country such as good hill country where crossing with the Border Leicester would take place and from which all the crossbred ewes would be sold as ewe lambs or two-tooths to the fat-lamb producer. The percentages in each type would not be the same as at Ashley Dene because the lower lambing percentage on the harder hill country would necessitate more than 25% of the national ewe flock being in the replacement category. But it would allow the Corriedale and Romney breeders who now breed sheep for both the hills and the lowlands to concentrate on breeding sheep better adapted to hill country, leaving the Border Leicester to provide the fertility and milk production required in the fat-lamb ewe, and the Down ram to give the carcass conformation and early maturity for the fat lamb.

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EFFECT OF PLANE OF INTAKE OF TOTAL DIGESTIBLE NUTRIENTS ON RATE AND EFFICIENCY OF GAIN IN IDENTICAL-TWIN STEERS

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Summary

A study of the effect of different levels of intake of total digestible nutrients (T.D.N.) was made, employing three sets of identical twins.

One animal of each twin set was permitted a high, intermediate, then high T.D.N. intake during three experimental periods, the durations of which were 60, 40, and 40 days respectively. The other twin in each set was permitted a low, intermediate, then high T.D.N. intake during the same three experimental periods.

1. With the steady increase in T.D.N. intake, low-intake twins showed an average increase in daily live-weight gain and a slight decrease in net efficiency.
2. With the drop in T.D.N. intake during Period II, high-intake twins showed a marked average decrease in daily rate of live-weight gain, gross efficiency of gain, and net efficiency of gain.
3. Net efficiencies of gain were higher for the low-intake group than for the high-intake group in all three experimental periods.
4. In spite of differences in level of T.D.N. intake, low live-weight gains, and relatively high theoretical maintenance costs in Period I, low-intake twins averaged 87% of the live-weight gains of the high-intake-twins on 85% of the T.D.N. intake.
5. The application of these and other research results to the livestock industry has been discussed.

Literature

It has been reported[1, 2, 3] that, for best results, both commercially and energetically, animals should be fed without interruption on a high plane of nutrition. In areas such as New Zealand[3], Australia[4], South Africa[5], and western North America[6, 7], seasonal pasture growth varies markedly. The high cost and limited availability of supplementary feedstuffs renders a continuous high plane of nutrition a questionable economic practice.

More recently, research results have been published indicating that cattle having been subjected to a period of restricted energy intake, such as wintering, make compensatory gains upon the resumption of feed intakes approaching *ad libitum* levels[8, 9, 10]. Final weight of restricted-intake groups usually fell short of full-fed animals in a time-constant experimental period[11, 12]. In two experiments involving identical twins under stall-feeding conditions[13, 14], compensatory gains were complete when animals were fed to a live weight rather than for a time-constant period.

In contrast with experimental animals subjected to reductions in caloric intake only, poorly wintered range or hill-country livestock often realize very poor gains while being subsequently grazed on high-

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quality pasture *ad lib.* The difference is undoubtedly accounted for by the fact that poorly wintered cattle and sheep ingest inadequate amounts not only of energy but also of protein, vitamins (particularly carotene), and minerals. After an extensive review of literature, Huffman and Duncan[15] concluded that of all the naturally occurring dietary deficiencies that effect the productivity of farm livestock, shortages of dietary energy is primary. In comparison with these shortages, deficiencies of protein and particularly vitamins and minerals, which are important in isolated instances, occupy a very secondary place.

The research reported here was undertaken in 1955 at Ruakura to determine the effect of a reduction in energy intake on subsequent rate and efficiency of gain.

Experimental Procedure

Three sets of two-year-old identical-twin Jersey steers were employed; one twin of each set being randomly selected for each of the two experimental treatments. All animals were housed together in an open shed with a concrete floor. Wood shavings were used for bedding and furnished as required. Each animal was fed twice daily at a uniform time in individual stalls. All offered and unconsumed feed was weighed daily to determine intakes. Water was available through automatic drinking troughs.

The rations of hay and concentrates met U.S. National Research Council[16] estimated requirements for crude protein, minerals, and vitamins. Daily intakes of total digestible nutrients were altered in each of the three experimental periods (Fig. 1A). In Period I, which lasted approximately 60 days, one twin of each set ingested a daily average of 12.4 lb. T.D.N., the other ingested a daily average of 8.1 lb. T.D.N.

Both twins in each set were offered the same average daily intake in Periods II and III which amounted to approximately 10.85 lb. T.D.N. and 12.15 lb. T.D.N. respectively. Periods II and III were of 40 days duration each.

All twins were individually weighed once weekly at a uniform time.

Results and Discussion

Period I. Weight and Efficiency of Gain during the Period of High and Low T.D.N. Intake

Weight gains and T.D.N. intakes for all three experimental periods are shown in Table 1. Throughout the presentation and discussion of results of all three periods, the animals that received the higher level of T.D.N. during Period I are referred to as the high-intake group while their counterparts are referred to as the low-intake group.

During Period I each animal followed the weight-gain pattern expected according to U.S. National Research Council recommendations[16]. The high-intake twin in each pair exceeded the low-intake twin's weight gain by a sizeable margin. It is also interesting that variation in weight gain and efficiency of gain was almost as great between similarly fed animals as it was within twin pairs upon whom an experimental treatment had been imposed. It may be seen that,

TABLE 1. Weight Gain and Total-digestible-nutrient Intake of Identical-twin Steers

No.	Group[1]	Days	Live Weight (lb.) Initial	Final	Gain Total	Gain Day	T.D.N.[2] Intake Total	Per lb. L.W.[3] Gain	Per Animal Per Day	% of High Twin
Period I										
9	H	60	650	800	150	2.50	754	5.03	12.6	100
10	L	60	655	715	60	1.00	489	8.15	8.1	65
25	H	59	659	795	136	2.31	733	5.39	12.4	100
26	L	59	674	750	76	1.29	480	6.32	8.1	66
29	H	59	668	766	98	1.66	725	7.40	12.3	100
30	L	59	668	726	58	0.98	480	8.28	8.1	66
Ave.	H	59	659	730	128	2.16	737	5.76	12.4	100
	L	59	666	787	65	1.09	483	7.47	8.1	66
Period II										
9	H	39	800	820	20	0.51	410	20.50	10.5	100
10	L	39	715	773	58	1.49	424	7.31	10.9	103
25	H	40	795	821	26	0.65	443	17.04	11.1	100
26	L	40	750	794	44	1.10	452	10.27	11.3	102
29	H	40	766	796	30	0.75	429	14.30	10.7	100
30	L	40	726	782	56	1.40	421	7.52	10.5	98
Ave.	H	40	787	812	25	0.64	427	16.84	10.8	100
	L	40	730	783	53	1.33	432	8.21	10.9	101
Period III										
9	H	40	820	856	36	0.90	484	13.40	12.1	100
10	L	40	773	851	78	1.95	483	6.19	12.1	100
25	H	40	821	892	71	1.78	486	6.85	12.2	100
26	L	40	794	867	73	1.83	482	6.60	12.1	99
29	H	40	796	849	53	1.33	488	9.21	12.2	100
30	L	40	782	820	38	0.95	487	12.82	12.2	100
Ave.	H	40	812	866	53	1.33	486	9.12	12.2	100
	L	40	783	846	63	1.58	484	7.67	12.1	100

1. H = high-intake group L = low-intake group
2. T.D.N. = Total digestible nutrients. Values calculated from Morrison (2).
3. L.W. = Live weight.

while the low-intake group ingested approximately two-thirds of that eaten by the high-intake group, they realized only half the live-weight gain. This is to be expected, since maintenance requirements utilize a much greater proportion of the ingested T.D.N. in the low-intake group leaving relatively little energy for weight increase. T.D.N. intake per pound live-weight gain shows that the efficiency of the low-intake twins[16]. The high-intake twin in each pair exceeded the low-intake spite of the fact that with a greater velocity of live-weight gain maintenance requirements for the high-intake twins exceeded those of their low-intake counterparts.

Using Morrison's tables[2] and data published by the Canadian Department of Agriculture[17], an estimate of net efficiency of gain was calculated (Table 3). As expected, the low-intake animals returned a higher net efficiency estimate than the high-intake twins.

Period II. Weight and Efficiency of Gain During a Period of Moderate T.D.N. Intake

In paired feeding experiments, it is customary in the second or subsequent experimental periods either to raise the plane of nutrition of the low-intake group to that of the high-intake group or to follow a cross-over experimental design[13, 14, 18]. By reducing the T.D.N. consumption of the high-intake group and raising the T.D.N. consumption of the low-intake group to a common intermediate level, two effects may be compared simultaneously.

The response of the high-intake group to the reduction in dietary intake was dramatic. With a decrease of only 1.6 lb. T.D.N. per animal per day, the average daily gain in Period II was only 30% of that realized in Period I, having dropped from 2.16 to 0.64 lb. live weight per animal per day (Table 2). In each comparison the high-intake twin gained much less per day in Period II than did its counterpart in the low-intake group. This may be partly but not fully explained on the basis of alimentary fill and maintenance costs, which were greater in high-intake than in low-intake animals.

The effect of low daily gains by the high-intake group during Period II was reflected in calculated efficiencies of gain. Whereas the average efficiency of gain of the high-intake groups was 5.76 lb. T.D.N. per lb. live-weight gain during Period I, it decreased almost threefold to 16.84 lb. T.D.N. per lb. live-weight gain during Period II. In Period II the average daily rate of gain of the low-intake group rose from 1.09 to 1.33 lb. per animal per day while the average efficiency of gain decreased slightly from 7.47 to 8.21 lb. T.D.N. per lb. live-weight gain. In each set of twins both the rate and efficiency of gain of the low-intake twin exceeded that of its high-intake counterpart in Period II. Two of the low-intake animals were more efficient during Period II than during Period I.

On calculating net efficiencies of gain for Period II, it was found that T.D.N. intake over maintenance was lower for the high-intake group and much higher for the low-intake group than those realized in Period I. Net efficiency of gain for the high-intake group decreased during Period II from 3.31 to 8.14 lb. T.D.N. per lb. gain, a decrease in efficiency of approximately 175%. The calculated average net efficiency

of gain for the low-intake group decreased during the same period from 2.73 to 4.08 lb. T.D.N. per lb. gain, a decrease in efficiency of approximately 50%.

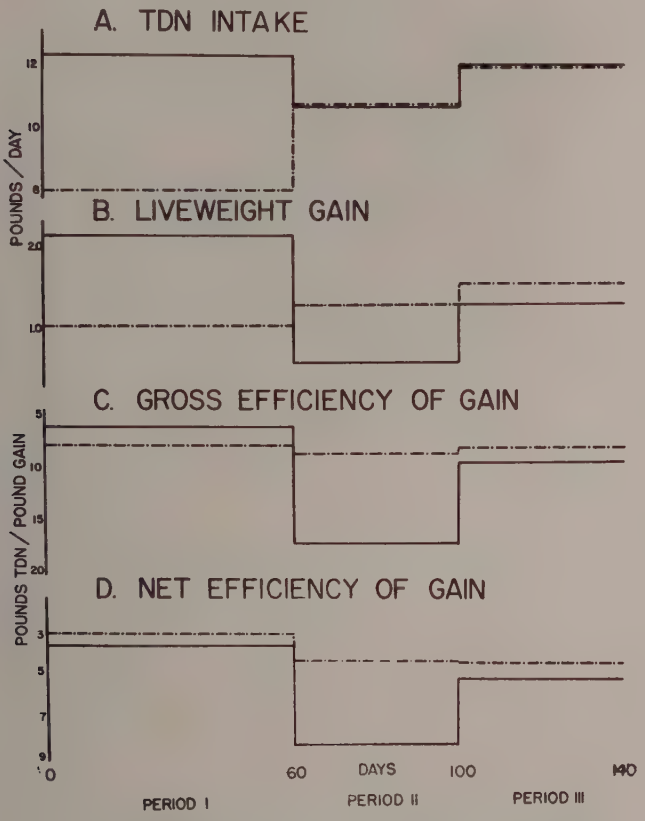

Fig. 1.—Average daily T.D.N. intake, liveweight gain, gross efficiency of gain, and net efficiency of gain of experimental identical twin groups.

Combining results from Periods I and II, it may be seen (Table 2 and Fig. 1) that the average live-weight gain realized by the high-intake group exceeded by 36 lb. the average gain of the low-intake group. In each set of twins the gains of the twin that received a high intake exceeded those of the low-intake twin. There was surprisingly little difference between groups in efficiency of gain. Average efficiency per lb. live-weight gain for the combined Periods I and II was 7.60 for the high-intake group and 7.80 for the low-intake group, a difference of less than 3%. There was a 24% difference in total T.D.N. intake and a 22% difference in total gain during the combined periods.

TABLE 2. WEIGHT GAIN AND TOTAL-DIGESTIBLE-NUTRIENT INTAKE OF IDENTICAL-TWIN STEERS

No.	Group	Days	Live Weight (lb.) Initial	Final	Gain Total	Gain /Day	Pounds T.D.N. Intake Total	/lb. L.W. Gain	/Animal /Day	% of High Twin
Periods I and II combined										
9	H	99	650	820	170	1.72	1164	6.85	11.8	100
10	L	99	655	773	118	1.19	913	7.74	9.2	78
25	H	99	659	821	162	1.64	1176	7.26	11.9	100
26	L	99	674	794	120	1.21	932	7.77	9.4	79
29	H	99	668	796	128	1.29	1154	9.02	11.7	100
30	L	99	668	782	114	1.15	901	7.90	9.1	78
Ave.	H	99	659	812	153	1.55	1165	7.60	11.8	100
	L	99	666	783	117	1.19	915	7.80	9.2	79
Periods II and III combined										
9	H	79	800	856	56	0.71	894	15.96	11.3	100
10	L	79	715	851	136	1.72	907	6.67	11.5	101
25	H	80	795	892	97	1.21	929	9.58	11.6	100
26	L	80	750	867	117	1.46	934	7.98	11.7	101
29	H	80	766	849	83	1.04	917	11.05	11.5	100
30	L	80	726	820	94	1.18	908	9.66	11.4	99
Ave.	H	80	787	866	79	0.99	913	11.61	11.5	100
	L	80	730	846	116	1.45	916	7.92	11.5	100
Periods I, II and III combined										
9	H	139	650	856	206	1.48	1648	8.00	11.9	100
10	L	139	655	851	196	1.41	1396	7.12	10.0	85
25	H	139	659	892	233	1.68	1662	7.13	12.0	100
26	L	139	674	867	193	1.39	1414	7.33	10.2	85
29	H	139	668	849	181	1.30	1642	9.07	11.8	100
30	L	139	668	820	152	1.09	1388	9.13	10.0	85
Ave.	H	139	659	866	207	1.49	1651	7.99	11.9	100
	L	139	666	846	180	1.30	1399	7.76	10.1	85

Period III. Weight and Efficiency of Gain during a Period of High T.D.N. Intake

During Period III, average intake of both groups was increased to the approximate T.D.N. level ingested by the high-intake group during Period I. With the increase in daily T.D.N. intake, daily rate of live-weight gain of the high-intake group more than doubled from a Period II average of 0.64 lb. to 1.33 lb. This was achieved with an increase in T.D.N. consumption of only 1.4 lb. per animal per day. During the same period, the low-intake group achieved an increase in daily rate of gain of 0.25 lb., rising from 1.33 to 1.58 lb. live-weight gain per animal. Neither group equalled gains made by the high-intake group during Period I probably because of the relatively higher maintenance costs in Period III.

The low-intake group exceeded total live-weight gains made in Period II by 10 lb. and Period III gains of the high-intake group by the same amount. Only two of the low-intake animals exceeded the live-weight gains realized by their high-intake twins during Period III. In the third set, the low-intake twin gained 15 lb. less than its high-intake twin. In spite of this unexplainable difference, the low-intake twin exceeded the gain realized by the high-intake twin during Periods II and III combined. While the decrease in efficiency of the low-intake group was slight in Period III compared with Period II, the increase in efficiency realized by the high-intake group was large, rising from a Period II average of 16.84 to 9.12 lb. T.D.N. per lb. live-weight gain. The low-intake group was again more efficient than the high-intake group with an average efficiency of gain of 7.67 lb. T.D.N. per lb. live-weight gain. This becomes more apparent when maintenance costs are considered. On calculating net efficiencies of gain for Period III, it was found that, because of differences in body weights in each set of twins, the intake over maintenance was greater for animals of the low-intake group. The calculated average net efficiency of gain was also higher, being 4.15 and 4.85 lb. T.D.N. per lb. live-weight gain for the low-intake and high-intake groups respectively.

TABLE 3. Calculated Net Efficiency of Gain during the 3 Experimental Periods[1]

	Period			
	Group	I	II	III
Average net efficiency of gain[2]	H	3.31	8.14	4.85
	L	2.73	4.08	4.15

1. Calculated using tables from Morrison[2] and the Canadian Department of of Agriculture[17].
2. Calculated by dividing T.D.N. intake over maintenance by daily gain.

Combining the results for Periods II and III, it may be seen (Table 2) that, after consuming the same daily and total T.D.N. intake, the average gain of the low-intake group exceeded the average live-weight gain of the high-intake group by 37 lb. It is evident that there

was a greater growth potential in the low-intake than in the high-intake group even at the end of the third experimental period. Some of the difference in gains may be attributed to differences in maintenance requirements for the two groups. The pooled results for Periods I, II, and III are shown in Table 2. It may be seen that the high-intake twins gained an average of 27 lb. more live weight while consuming 252 lb. more T.D.N. than the low-intake twins. Thus, in spite of the changes in rate and efficiency of gain shown by the high-intake group, particularly during Period II, and the low intakes of the low-intake group during Period I, there was little difference in efficiency of gain. The low-intake group averaged approximately 87% of the live-weight gain while consuming approximately 85% of the T.D.N. ingested by the high-intake group. Calculated maintenance costs for the low-intake group were 87% of those required by the high-intake group for the total experimental period. Calculated net efficiencies of gain were better for the low-intake group than for the high-intake group in each of the three experimental periods, yet there was little or no average difference between groups in gross efficiency of gain for the entire experimental period. It must be concluded that, based on controlled intake levels, high relative maintenance costs for the low-intake group in Period I were offset by the higher maintenance costs of the high-intake group during Periods II and III. The relevant data are summarized in graphical form in Fig. 2.

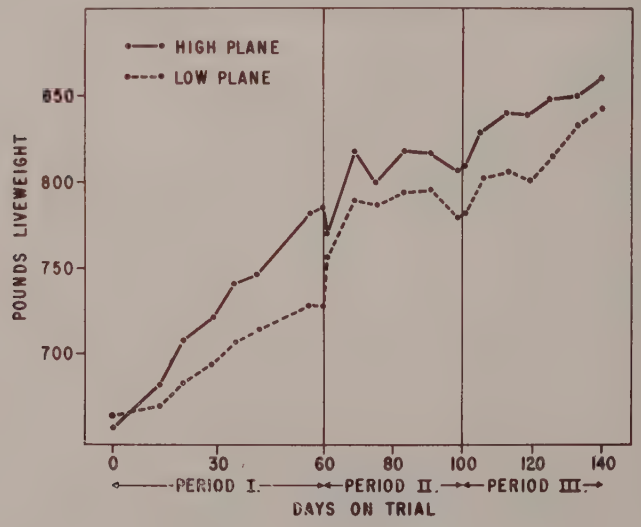

Fig. 2.—Live weights of high-plane and low-plane groups.

The data presented suggest that retardation of weight gain in two-year-old steers did not adversely influence subsequent efficiency of gain. An increase in gross efficiency due to lower maintenance requirements after a period of reduced energy intake ended accounts for the fact that there was almost no difference in the amounts of feed required to produce a unit of live-weight gain. This conclusion is in keeping with results of recent and more extensive work by Winchester and Howe[14].

Based on these and previously reviewed experimental results, certain recommendations applicable to the livestock industry may be made. At ages of six months or more, cattle may be maintained for at least two to six months *on a diet providing at least maintenance energy requirements and other classes of nutrients at levels adequate for growth.*

These results indicate that if feedstuffs providing energy in amounts supplementary to those available in pasture are cheap enough to permit cattle producers to provide profitably a high level of nutrition throughout the year, this should be done. Such a programme permits the marketing of young animals and a more rapid return from capital invested in feed, facilities, and cattle. It also permits the marketing of livestock at times which are out of phase with normal seasonal livestock production. However, as is more commonly found, prices of feedstuffs providing energetic compensation for marked seasonal variations in pasture production are so high that it is not economically feasible to use them in the large amounts necessary for a continuous high rate of growth. In such cases, retarded growth is equally efficient energetically and much more profitable economically. These results would further suggest that a reduction in energy intake is metabolically upsetting to the animals. It may even prove to be energetically more profitable to restrict feed intake during periods of plenty and store surplus feed for use during periods of shortage to provide a continuously increasing energy intake.

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BUMBLE BEE SPECIES PRESENT IN THE SOUTH ISLAND OF NEW ZEALAND

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(*Received for publication, 16 August 1957*)

Summary

On the basis of collections made in 155 different localities throughout the South Island of New Zealand it is established that four species: *Bombus terrestris* (L.), *B. ruderatus* (Fab.), *B. subterraneus* (L.) subsp. *latreillellus* (Kirby), and *B. hortorum* (L.) occur there.

B. terrestris and *B. ruderatus* are present throughout the island, while *B. subterraneus* subsp. *latreillellus* and *B. hortorum* appear to be confined to the eastern side of the main divide south of Balcairn in north Canterbury.

After a number of unsuccessful attempts from 1870 onwards, bumble bees were finally established in New Zealand in 1885. From two consignments from England in January and February of that year, the Canterbury Acclimatisation Society liberated 93 queen bumble bees near Christchurch. They rapidly spread throughout the island and by 1890 had reached Invercargill. No record was kept of the species liberated; hence in 1895 when the society sought advice on further importations they deemed it necessary to send specimens to Miss E. A. Ormerod (formerly Entomologist to the Royal Agricultural Society of England) for identification. She reported that *Bombus terrestris* and *B. subterraneus* were present. Sladen (1912) states that up till that time British authors applied the name *subterraneus* to the species now known as *ruderatus*. A perusal of Miss Ormerod's letter (by courtesy of the Secretary of the North Canterbury Acclimatisation Society) shows that she was in fact referring to *ruderatus*. She says "among your specimens I have found a queen and three workers, . . . entirely black except the apex of the abdomen which is fuscous." Only *ruderatus* in the whole genus *Bombus* exhibits this degree of blackness. Of the striped specimens she states definitely that they are sufficiently different from *B. hortorum* to say that they were not that species and her description of them does not tally with that of *B. subterraneus* subsp. *latreillellus*. *B. terrestris* and *B. ruderatus* then were definitely established in New Zealand by 1895. The next attempt at importation of bumble bees was made by the Canterbury Agricultural and Pastoral Association in 1906, when from three consignments received from England in February, November, and December, 143 queens were liberated. Hopkins (1914) quotes two letters written to him by Mr. O. B. Pemberton, the secretary of the association. One written in January 1913 referring to the species imported by the association in 1906 in which he states, "The queens we got out were *B. lapidarius* and *B. hortorum*", and in the second letter written in August 1913 he states, "Re species imported (by the Canterbury Agricultural and Pastoral Association): (1) *B. lapidarius;* (2) *B. hortorum;* (3) *B. hortorum* (variety *harrisellus*); (4) *B. hortorum* (variety *subterraneus*); (5) *B. derhamellus*. The majority of the bees which arrived alive were species 1, 2, and 3."*

*Both *harrisellus* and *subterraneus* as here used are synonyms of *ruderatus*.

Hopkins (1914) attempted to discover which species had successfully established here and believed that the following species occurred:—

B. terrestris (L.), *B. ruderatus* (Fab.), *B. hortorum* (L.), and *B. lucorum* (L.) (probably). Next, McBurney (1941), on the basis of a year's study carried out at Lincoln, considered that all four species mentioned by Hopkins (1914) were present in Canterbury. He found *B. subterraneus* (L.) subsp. *latreillellus* (Kirby) there also. Dumbleton (1949) carried out a survey from Nelson to south Canterbury in February–March 1947 and found only *B. terrestris, B. ruderatus,* and *B. subterraneus* subsp. *latreillellus,* as did Montgomery (1951) in a survey of the whole of the South Island in 1949–50 (both authors had their specimens determined by Professor O. W. Richards, London). Dumbleton (1949) states, "*B. hortorum* was not present, and as the collection covered a wide area, is presumably not present in the country. Since all the specimens of the presumed *terrestris* were not submitted for determination there remains a doubt as to whether *lucorum* is present or not."

The present survey was started in 1953 and has been continued annually. Collections have been made in 155 different localities throughout the South Island.

B. terrestris and *B. ruderatus* were found to be present throughout the island.

B. subterraneus subsp. *latreillellus* was taken at Cromwell only, but McBurney (1941) found it at Lincoln, Montgomery (on file Entomology Division, Department of Scientfic and Industrial Research) records it from Clydevale, and Dumbleton (1949) records it from Fairlie, Hakataramea, and between Surrey Hills and Mayfield.

B. hortorum (identification confirmed by Professor O. W. Richards, London) was found to be present not only in Canterbury but in Otago and Southland also. This species was recorded from 37 different localities. Further work will be necessary to delimit exactly its range, but so far it has not been found west of the eastern limit of the main divide (Ben More) or further north than Balcairn in Canterbury. Although the bulk of the present collections, especially of *B. ruderatus* the most nearly related species, comes from Nelson, Marlborough, and Westland, no specimens of *B. hortorum* have been taken in these districts; it seems likely therefore that it is in fact confined to Canterbury, Otago, and Southland.

B. lucorum was not found, although special visits were made to localities where McBurney (1941) stated that this species occurred. Since only one specimen labelled *B. lucorum* by McBurney remains at Lincoln College and this is definitely *B. terrestris,* it seems likely that his claim for the presence of *B. lucorum* was based on misidentification. Neither did Hopkins (1914) claim to have found this species for he states, ". . . it being so very like its near relative *B. terrestris,* I think it more than likely that we have it". This species therefore has never been taken in New Zealand and identified beyond doubt.

B. lapidarius apparently failed to establish here. Sladen (1912) says Dr. Hilgendorf informed him that "up to November 1911 no specimens have been seen flying." Mr. O. B. Pemberton writing to

Hopkins in 1913 states, "I have not heard of any of the *B. lapidarius* being seen so I presume they did not live." None have been recorded from New Zealand.

B. derhamellus was also mentioned by Mr. Pemberton but he implies that few if any were liberated. None have been recorded from New Zealand.

Both these species are conspicuous insects, black with the last three abdominal segments of the abdomen red, quite distinct from the familiar yellow-striped bumble bees whose terminal abdominal segments are white or fawn. The possibility that such conspicuous insects could have remained unnoticed for the past 50 years is so remote that it can be safely assumed they are not present.

It is now established from the information gained on the present survey that, of the seven species, either claimed or thought to have been liberated in New Zealand, four species—*B. terrestris, B. ruderatus, B. hortorum,* and *B. subterraneus* subsp. *latreillellus*—occur at present in the South Island. *B. lucorum, B. lapidarius,* and *B. derhamellus* were not found. *B. lapidarius* and *B. derhamellus* have never been found, but McBurney (1941) claimed to have found *B. lucorum* although there is doubt about his identification of the species. There still remains, therefore, a remote possibility that *B. lucorum* may be found, but not *B. lapidarius* or *B. derhamellus.*

Contrary to the findings of the two previous surveys (Dumbleton in 1947 and Montgomery in 1949–50) *B. hortorum* was shown to be present and relatively numerous throughout its range. This species is a long-tongued bumble bee, particularly desirable as a pollinator of red clover. Each time it has been suggested that new species should be introduced in order to increase pollination and thus seed set in red clover, *B. hortorum* has been high on the priority list. It is shown now that this species no longer needs to be considered in this respect for it is here already.

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Appendix

The following key and diagram (after Dumbleton (1949) but altered and added to) give the salient differences between the queens of the four species of bumble bees now known to be present in the South Island of New Zealand. The workers do not show the characters so clearly. In cases of doubt the queens may be identified by the structure of the inner projection of the sting sheath and the males by the structure of their genitalia. These structures are figured by Richards, O. W. 1927: The Specific Characters of the British Humble bees (Hymenoptera). *Trans Ent. Soc. Lond. 75:* 233-68.

Key to Bombus Species in New Zealand

(1) A single (anterior) yellow band on the thorax, a prominent broad yellow band on the second abdominal segment, posterior third of 4th and the whole of 5th abdominal segment tawny, short tongued ..... *B. terrestris*

Two yellow bands (anterior and posterior) present on the thorax, long tongued 2

(2) Anterior and posterior yellow bands on thorax of equal width, yellow colouration on abdomen confined to 1st abdominal segment and most strongly developed laterally, always interrupted in the middle by more or less black, the posterior margin of 3rd abdominal segment white laterally, 4th and 5th abdominal segments white ..... *B. ruderatus*
(All transitional stages occur between completely black form and normally banded forms.)

Posterior thoracic yellow band narrower than anterior one, yellow band on abdomen occupying the whole of 1st abdominal segment and extending onto anterior margin of 2nd abdominal segment, bands bright lemon yellow, posterior margin of 3rd abdominal segment white laterally, 4th and 5th abdominal segments white, coat uneven and longer than in *ruderatus*, head more elongate than other species, nearly twice as long as it is broad ..... *B. hortorum*

Posterior thoracic yellow band narrow, half the width of anterior, anterior yellow band invaded in the middle of the hind margin by a darker area, yellow colour on abdomen, confined to lateral margins of 1st and posterior margins of 2nd and 3rd abdominal segments, 4th and 5th abdominal segments white, coat short—very short on basal segments of abdomen, head shorter than *ruderatus* ..... *B. subterraneus* subsp. *latreillellus*

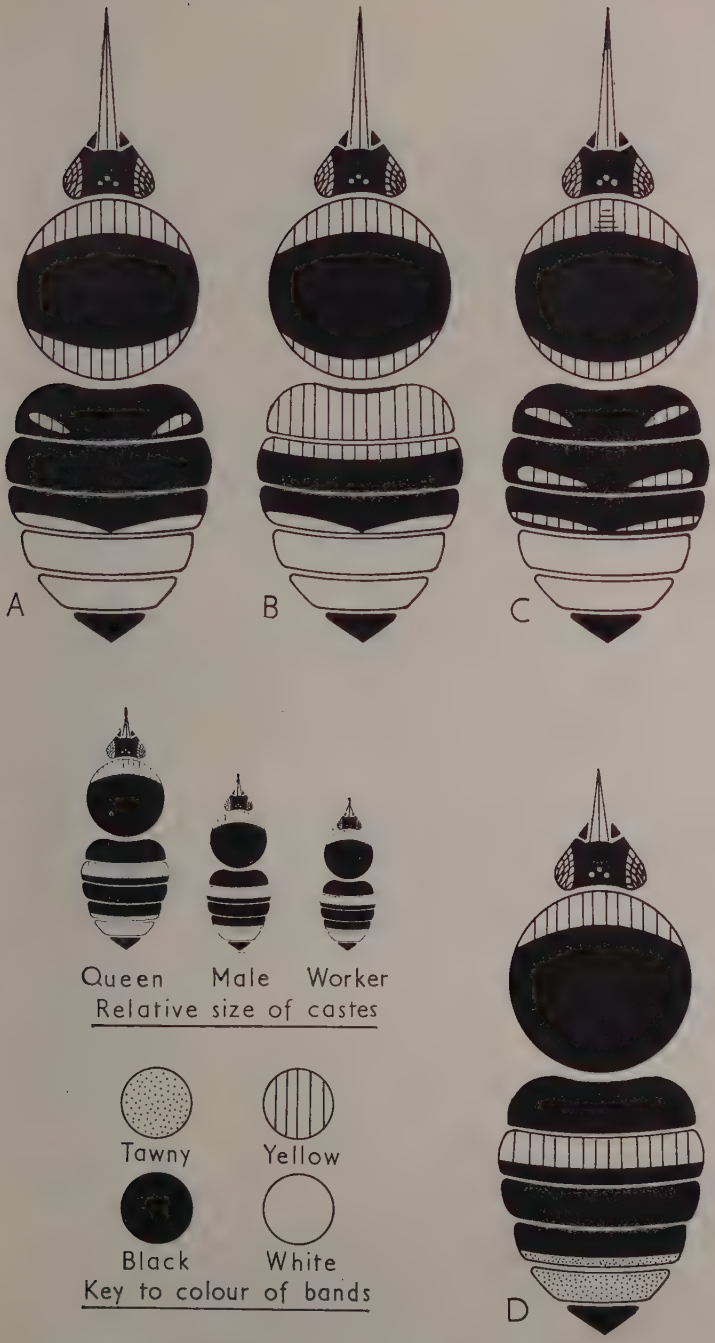

Fig. 1.—A. *B. ruderatus*. B. *B. hortorum*. C. *B. subterraneus* subsp. *latreillellus*. D. *B. terrestris*.

CORRIGENDUM

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